

RYERSON HANDBOOK —ON— TOOL and ALLOY STEELS



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CHICAGO

SHOP HANDBOOK

ON

Tool and Alloy Steels

*A technical subject
treated in a
non-technical way*

Tool Steel, Section I—Pages 7 to 58

Alloy Steel, Section II—Pages 59 to 128

BY

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JOSEPH T. RYERSON & SON INC.

ESTABLISHED 1842

SPECIAL STEELS

CHICAGO

ST. LOUIS

DETROIT

CLEVELAND

JERSEY CITY

MILWAUKEE

CINCINNATI

BUFFALO

BOSTON

Tool Steel Section

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Alloy Steel Section

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Introduction

Ryerson in Unique Position to Solve Tool and Alloy Steel Problems

For more than three-quarters of a century the Ryerson Company has been engaged in solving steel problems for manufacturers in all lines of business. During this time we have built up an organization unequalled for its ability to save time and money where steel or allied products are involved. We have also been in a position to study and experiment with the various types of steels developed and have been successful in including the best of these in our own stock.

The tool steel division of our Special Steels Department carries a large and complete stock of tool steel to meet practically every manufacturing requirement. The alloy steel division includes most of the standard alloy steels as well as some of our own particular alloys made up for some of the special mechanical needs of our customers.

This data book has been prepared to assist our friends and customers in securing and properly handling tool and alloy steels. The information is naturally limited, but it covers most of the practical applications.

We maintain an efficient technical staff and will be glad to give personal attention to your special requirements on request.

Eight complete Ryerson Steel-Service Plants provide for the immediate shipment of everything in Iron and Steel.

*Please use the Current
issue of the Ryerson
Journal and Stock List
—if you do not have a
copy write for it.*



BOSTON PLANT



JERSEY CITY PLANT



BUFFALO PLANT



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DETROIT PLANT



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ST. LOUIS PLANT



CHICAGO PLANT

Order from the plant nearest your shop.

Tool Steel—An Asset or Liability in Your Plant

TOOL STEEL that is purchased from a mill or a warehouse, is not, as a rule, a finished product. It is for this reason that we are putting this book in the hands of the tool steel user, for he is the one who must change the tool steel from a semi-finished to a finished product. For the successful carrying out of this operation certain definite information is necessary.

The manufacturer of tool steel may have devoted unlimited time, attention and experience to the selection of raw material and the working up of this material into the tool steel bar, which is ultimately shipped to some user. At this point, however, the life of the tool steel has merely started and its subsequent performance depends as much upon the treatment given by the tool hardener as upon any other factor. The hardening and tempering operations are equally as important as the making of the steel itself, and yet this work is frequently entrusted to operators of little experience and who are frequently required to work with very inadequate equipment.

The lack of understanding of tool steel hardening results every day in losses which are far greater than the average tool hardener realizes. These losses cover not only the value of the steel itself, but also the labor which has been expended on the tool prior to hardening, as well as loss of time and production in the shop. There is another source of loss which is frequently not recognized; that is, in the curtailment of production by the failure of the tool to operate at its best, even in

cases where this tool does not actually break, but merely fails to give the service it would have given had it received the proper heat treatment.

Many of our readers are very familiar with the hardening of tool steel and to them, of course, many statements made in this book will seem obvious. In putting out a book of this kind, however, we must assume that the reader has no knowledge of the subject whatever and therefore endeavor to give all the information that might possibly be required.

A great deal has been said and written about the relative value of definite methods of manufacture used in producing tool steels. Frequently great stress is placed by the manufacturer on the class of raw material from which his steel is produced. We would like to suggest to our readers that they estimate the value of any tool steel entirely on the basis of the results which they obtain from its use, rather than by considering the method used in its manufacture or the raw material from which it is made.

A manufacturer of tool steel is frequently asked to furnish the analysis of some special steel which he is offering. There should be no particular objection to giving this, but on the other hand there is seldom any real reason why the customer should need this data. The manufacturer can and will furnish complete information with reference to heat treatment and if, following such treatment, the steel proves either satisfactory or unsatisfactory, the matter of analysis is relatively unimportant.

The writer still adheres to the old-fashioned idea of classifying tool steel by a brand name rather than on an analysis basis. The brand stamped on a bar of steel very definitely connects the producing mill with that particular bar. It seems rather

obvious that where a manufacturer is putting his signature on each piece of material turned out, he is going to take a lot of care to see that the results obtained from the use of that bar are a credit to his mill. Tool steel could, to a certain extent, be furnished on an analysis basis, but on the other hand it must be remembered that two bars of steel can have practically the same analysis and yet be radically different in their several working characteristics. For this reason it is obvious that if the brand name is not used as a basis for purchasing, it will be necessary for the buyer not only to specify analysis, but also to cover such elements as the kinds and proportions of raw materials used, the method of melting, hammering, rolling, annealing, inspection and all the other hundred and one processes through which tool steel must go before it ultimately reaches the shipping platform.

Important

All ANNEALED tool steel must be ordered sufficiently oversize to allow complete removal of outer surface which has been decarbonized as a result of the annealing process. If this is not done, the surface of the steel will not harden.

(See pages 27 and 28.)

Choosing the Proper Steel for the Job

Help Your Toolmaker by Giving Him the Right Steel for
Each Job

IN SELECTING the tool steel for the production of any special tool, die or other part, two things must be taken into consideration; namely, the source of supply and the class of steel.

In deciding on a source of supply for tool steel, the first element to be considered is the reliability of the seller. The average purchaser has neither the time nor the equipment to conduct elaborate tests in order to determine the quality, analysis, hardening and durability characteristics of the steel which he is buying. He must, therefore, rely upon the information furnished by his source of supply.

It would seem evident that a well established, reliable concern would not willingly misrepresent the product which they are offering and, in the event that something did go wrong they would invariably stand behind their product. Promptness of service, availability of stock and geographical location will, of course, have a bearing in determining where to buy tool steel. The most important thing, however, is undoubtedly the selection of a concern that is willing and anxious to give their customers fair and square treatment and one which is responsible and able to render this service in a technical as well as a businesslike manner.

After having decided where the steel should be purchased, the next and rather more difficult step is determining what particular *kind* of steel shall be used.

As a rule, such tools as punches, dies, reamers, rivet sets, chisels, etc., can be made of several different grades of steel and it is sometimes rather confusing to the purchasing agent to decide which particular class of material is best suited to shop requirements.

Reference to another part of this book will show some of the principal uses to which different grades of tool steel are applicable and in the majority of cases a satisfactory decision can be reached by such reference. (*See pages 48 to 58.*)

Before deciding on any particular grade of steel it would be well to consider whether the shop has the necessary facilities for the proper hardening and tempering of the grade selected. For example, an oil hardening die steel requires a rather careful and accurate hardening treatment, whereas a low carbon common grade steel can successfully withstand considerable abuse and variation in the hardening temperature.

It is also true that a high carbon, special grade tool steel will make a die which will last longer than a die made of a lower carbon common grade steel. On the other hand, if the shop facilities consist of nothing more than an open fire and limited tool hardening knowledge, the chances are that the low carbon steel would actually produce a more serviceable die than the better grade material owing to the fact that it is not as delicate and, therefore, not as susceptible to damage through inexperienced treatment.

This is probably an opportune time to mention the subject of price or initial cost in so far as it pertains to the purchase of tool steel. It is true that the original cost of the tool steel which is used in making a die is of absolutely no consequence whatsoever. The majority of purchasing agents will probably doubt this statement, but if the life

history of any die is followed through completely it would be conclusive proof that the raw material cost is a negligible factor.

In the first place the labor which is expended on a die or tool will usually amount to many times the cost of the raw material, and if after completion the die or tool has an increased efficiency of 5%, it must be remembered that the benefit derived is cumulative and goes on increasing hour after hour as long as the tool is in service.

When the matter of tool steel selection can not be settled clearly without any doubt, it is a very good plan to put the matter up to some good, reliable source of supply. The chances are that they have been furnishing a certain grade of steel to meet a similar problem in some other shop and, therefore, can give you advice based on experience rather than theory. Such information service is always rendered gladly and the purchasing agent should avail himself of it, inasmuch as it is one of the things that he is paying for when approving the tool steel invoice.

We would like to digress a little at this point and emphasize the importance of specifying the correct sizes of tool steel, inasmuch as this is just as necessary as the selection of a source of supply and the grade.

It is a fact that annealed tool steel as received from the mill will not harden on the outside surface. Just why this is will be explained later on, but for the time being we must ask the reader to accept the fact as being true.

We feel safe in saying that half of the claims that have come in to us on tool steel are caused by the purchaser's failure to realize that he can not expect a piece of annealed tool steel to harden on the outside surface. The result is that after the first attempt at hardening the steel is found to

be soft. The tool hardener thinks that he has not used a high enough temperature, so he puts the steel in the furnace again and heats it to a higher point, repeating this operation with increasing temperatures until the tool has been absolutely ruined beyond redemption.

The answer to this difficulty, of course, lies in the purchase of a piece of steel sufficiently large so that a machine cut can be taken all over the outside surface. This will insure a good hard surface on the first quench and will save a lot of time and money by avoiding cracked and burnt material.

Important

All ANNEALED tool steel must be ordered sufficiently oversize to allow complete removal of outer surface which has been decarbonized as a result of the annealing process. If this is not done, the surface of the steel will not harden.

(See pages 27 and 28.)

Heat Treatment of Tool Steel

Without Proper Heat Treatment, Tool Steel Is but Little
Better Than Mild Steel

IN ANOTHER part of this book we will give the specific hardening, tempering and annealing instructions for the various grades of steel. There are, however, certain definite general principles which govern the heat treatment of practically all tool steels irrespective of the grade or brand.

It will be our purpose in this chapter to show in a non-technical way just what happens when tool steel is hardened and to bring to the reader's attention the most important of the fundamental principles of such changes.

Tool steel can exist in four different states at normal room temperature. These four states are the normal or natural condition of the steel as it comes from the rolling mill or hammer shop. Second, the annealed condition. Third, the fully hardened condition, and fourth, the tempered semi-hardened condition wherein the steel has been fully hardened but has had some of the hardness removed by a tempering or drawing operation.

Consider for a moment what happens to a piece of tool steel when it is hardened. As a piece of steel is raised to a certain temperature, varying with the analysis of the steel, certain changes take place in the metal. The point at which these changes occur on a rising temperature we will call the "critical temperature No. 1." Many good technical books may be obtained which cover this subject very thoroughly, but inasmuch as we desire to avoid technicalities in this hand book,

we will ask our readers to accept the fact that such a change point or critical temperature exists.

The changes taking place in a piece of steel when it is heated above the "critical temperature No. 1" are such that if the steel could be retained in its changed condition at ordinary normal temperature the physical properties of the steel would be entirely different to those which it possessed prior to the change having taken place. This changed condition of the steel if complete at normal room temperature would produce the greatest possible hardness and cutting ability, which of course is partly the object of all tool steel hardening.

It is very important that we remember that the changes which occur in a piece of steel when heated above the "critical temperature No. 1" do not take place instantaneously, a certain period of time being necessary for the transformation of the metal, both on a rising and falling temperature. It is by taking advantage of this time element or lag that we are able to harden a piece of tool steel.

We have already stated that a change takes place in steel when the temperature is raised above the "critical temperature No. 1," and it is equally true that a reversal of this change takes place on a decreasing temperature, although the change point (which we will call "critical temperature No. 2") is somewhat lower than "critical temperature No. 1."

The changes which we have mentioned as occurring in a piece of steel during the heating operation can only occur in the presence of heat, and if, therefore, we raise a piece of steel above the "critical temperature No. 1" and cool it more rapidly than a reversal of these changes can take place, we will have fixed in the steel at least a portion of these changed characteristics. This is exactly

what is done when a piece of tool steel is heated and quenched.

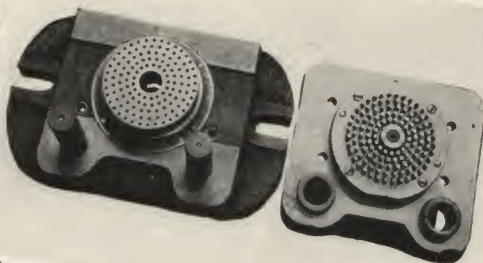
A brief summary of the foregoing statements is somewhat as follows:

1. That steel undergoes a definite change when heated above a certain temperature.
2. That the tendency of the steel is to return to its normal condition during the cooling process.
3. That the change to normal condition during the cooling process takes a certain amount of time.
4. That if the steel can be cooled by quenching, or some other method, more rapidly than the changes can reverse themselves, then we will have fixed in the steel certain of the changed characteristics.

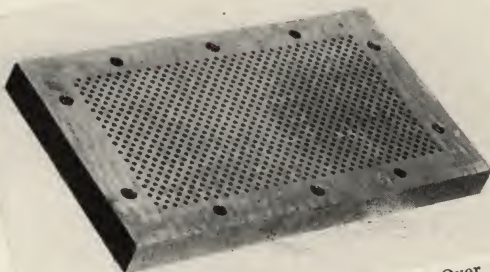
At this point it will probably be in order to mention the influence of size on the method employed in the hardening of tool steel. We have emphasized that the rate of cooling is of vital importance and quite obviously a 6" round bar can not be cooled as rapidly as a $\frac{1}{2}$ " round bar. This point must be borne in mind in order that allowance can be made for the different rate of cooling of different sizes of tools, dies, etc.

Considering a piece of tool steel which has been heated above the "critical temperature No. 1" and quenched as rapidly as possible, we now know that this steel will have its maximum obtainable hardness and will in all probability be too hard and brittle for ordinary shop use.

In order to partially reduce this hardness and to increase the toughness of the steel, it is necessary to resort to a drawing or tempering operation. When steel has been hardened it is in very much the same condition as a clock spring that has been wound up as far as possible, inasmuch as it has a tendency to return to its normal condition. Such a return is, of course, prevented by the fact that the steel is cold and that these changes can only



Perforating die, made of
Ryolite B-F-D Oil Hardening
Tool Steel.



Perforating die. Over 1,800
holes, accuracy within 1-1,000
inch. Made of "Ryolite
B-F-D."



Die for working heavy gauge
steel. Punches four odd-
shaped holes at one operation.
Made of "Ryolite XXX."

Dies shown through courtesy of Premier
Tool Works, Chicago.



Typical carbonizing or tool hardening furnace, such as used in the average shop. Note the steel canopy over the furnaces, arranged to carry off the fumes and gases. The operator is shown placing in the furnace a carbonizing box, containing the parts packed in a carbonizing mixture.

occur in the presence of heat. The point at which the reversal of the hardening changes can start will vary in different steels, but is in the majority of cases about 300° Fahrenheit. The amount of reversal that can take place increases as the temperature is raised until this temperature has reached the "No. 1 critical," at which point the reversal or change will be complete.

In shop practice a tempering or drawing heat of from 300° to about 700° is used in order to produce varying degrees of hardness and toughness as required for the tools which are being made.

When tool steel is to be machined, it is put through what is known as an "annealing process." This process consists of nothing more than raising the temperature of the steel to a point beyond the "critical temperature No. 1," after which it is allowed to cool as slowly as is commercially possible. This slow cooling is, of course, the opposite of the quenching operation, inasmuch as it affords the steel every opportunity to eliminate the changes which took place during the heating operation.

Heating Tool Steel

An Operation Requiring Knowledge and Care

All hardening and tempering operations as applied to tool steel involve the use of heat and we will, therefore, devote a little time to the consideration of the various methods of applying heat and its several effects.

Probably the most important thing to consider when heating tool steel is the rate at which the heat is applied. It is quite obvious that when a piece of steel is placed in the furnace the heat must reach the center of the steel by conduction. In other words, the temperature of the outside portion of the steel is increased and the heat then

travels from one particle of metal to another until it has finally reached the center. This process continues until such time as the entire mass of metal has reached a temperature equal to that of the furnace itself.

We all know that when a piece of metal is heated it expands. This expansion is proportional in amount to the temperature change. If we, therefore, place a piece of cold steel in a hot furnace, the outside will increase in temperature more rapidly than the inside, therefore causing a differential expansion, so that the outside surface of the steel will actually increase in size much more rapidly than the underlying layers.

In certain steel this rapid change does not make very much difference, inasmuch as the steel is sufficiently soft and ductile to stand considerable motion without harmful effects. A majority of tool steels, and particularly steels of a dense, close grain structure, such as high speed steel, chrome hot work steel, and other alloy tool steels, can not stand much change of shape when in a relatively cold condition, consequently these steels will frequently crack if placed directly in a hot furnace.

It will be obvious from these remarks that the safe way to heat tool steel is to raise the temperature gradually, either by placing the steel in a cold furnace and allowing it to increase in temperature as the furnace comes up, or by preheating the steel to a reasonable degree before placing it in a hot furnace.

Where a large number of similar pieces are to be heated, it is good practice to use one or more preheating furnaces. For example, if it were necessary to heat a number of parts to 1,650° F., considerable time would be saved and correct heating will be secured by first placing the pieces in a furnace which is held at about 900° F. to 1,000° F.,

then in a second furnace at about 1,350° F. and finally in a third furnace which is held at the desired temperature of 1,650° F.

It is safe to assume that a large number of tool steel failures are caused by either too rapid heating or an incorrect heating atmosphere. This atmosphere can either be the products of combustion in a closed furnace of any type, or it may be the hot gases which are coming up from the bottom of a blacksmith's open fire.

For its hardening ability, tool steel depends primarily on the presence of carbon and if this carbon is removed it is quite natural that the steel will not successfully serve the purpose for which it is intended. Carbon and oxygen have, in the phraseology of the chemist, a strong "affinity" for each other. This is particularly true when the temperature of the carbon in the steel has been raised to a relatively high point. The affinity of these two elements is so strong that if a piece of tool steel is held at a hardening temperature in the presence of oxygen, this latter element will attack and form a combination with the carbon, thus removing it from the steel. This action explains many of the cases where a piece of perfectly good tool steel was heated to the correct hardening temperature and yet failed to harden on the outside when it was quenched.

It will now be quite easy to see why it is necessary to maintain what is known as a neutral or slightly reducing temperature in a furnace. If there is any excess of air used, oxygen in the air will attack the hot steel and the result will be a die that, while hard underneath, will have a soft skin or surface.

In order to be quite sure that there is no excess of air used in the furnace, it is a good thing to keep the atmosphere in the furnace slightly hazy.

By this we do not mean that a great deal of excess fuel should be used, but the presence of just a little haziness will indicate that sufficient fuel is being supplied so that all the available oxygen is taken up by the fuel and not by the carbon in the steel.

There is another advantage in using a very slight excess of fuel and that is in the elimination of scale. Tool steel can be hardened so that the surface is quite smooth and clean, whereas if there is an excess of air the surface will be rough and scaly, even in cases where the decarbonization has not gone deep enough to do any particular damage.

If a small amount of granulated charcoal is placed on the hearth of the furnace, but not actually touching the tool, practically all danger of decarbonization and the consequent forming of soft spots will be eliminated.

We would like to tell you how long a certain piece of steel should remain in the heating furnace. There are, however, too many variable factors, such as the furnace temperature, kind of steel and the sizes of the tools to make this possible. Sufficient time must be allowed for the desired temperature to penetrate uniformly throughout the piece, but once this result has been secured the steel should be removed, inasmuch as continued heating or "soaking" is detrimental to the tool steel. Another good means of preventing decarbonization consists of coating the surface of the die with copper before it is placed in the furnace. This is done by dipping the clean die in a strong solution of copper sulphate (blue vitriol). The die must be clean and entirely free from grease, and should be washed in water before it is placed in the furnace. The film of copper has a tendency to absorb the free oxygen, thus preventing its acting on the carbon of the tool steel.

A molten lead bath is a very convenient medium for heating tool steel, provided that accurate temperature measurement is available and also that a sufficiently large number of pieces are to be heated. Inasmuch as a lead bath imparts its heat very rapidly, it is generally necessary to preheat the steel before placing it in the lead in order to avoid a too rapid increase in the temperature. It is important that the lead bath be held at a temperature not in excess of that to which it is desired to heat the steel. The lead heats so rapidly that it is very easy to overheat the tools which are being treated. Pieces being heated in a lead bath are, of course, out of sight and it is therefore necessary to judge their temperature by using a pyrometer which measures the heat of the lead.

Do not attempt to heat a piece of steel to 1,400° F. in a furnace which is running at 1,600° F. In other words, hold your furnace at the temperature to which you desire to heat the steel and then leave the steel in the furnace for a sufficient length of time, so that the furnace and the steel will both be at the same temperature. If the furnace is hotter than the temperature desired for the steel it is obvious that the steel will have to be removed as soon as the outside surface has reached the desired point. It is equally clear that at this particular time the inside of the steel will be lower in temperature than the outside because the heat has not had a chance to travel all the way through to the center. This condition, of course, is highly undesirable and is one of the causes of warped and cracked tools and dies.

When a piece of steel is heated and has reached a red color, the outside edges and projecting portions will appear hotter than the lower or depressed parts. As long as this condition exists the temperature has not become uniform, but it is safe to assume that when these dark areas or,

as they are sometimes called, "shadows," disappear, the steel has attained a uniform temperature throughout. Provided the furnace has been held at the correct heat, the steel is ready to be taken out and quenched.

The essentials for the proper hardening of tool steel can be summarized briefly as follows:

1. Do not heat tool steel quickly. If the furnace is hot, warm your steel up before putting it in.
2. Remember that the heat has to travel by conduction from the outside of the piece to the inside. As it is necessary for the steel to be heated uniformly throughout, sufficient time must be allowed for the heat to penetrate and become equal all the way through to the center of the piece.
3. Be sure of your furnace atmosphere. It is advisable to use a slight excess of fuel, as an excess of air will produce tools with a scaly, soft surface.

Heating Equipment

It Pays to Use Good Equipment

There are several kinds of furnaces used for heating steel, such as the gas furnace, the oil furnace, the coal or coke furnace, the electric furnace and the blacksmith fire.

Just which constitutes the best method of heating will, of course, depend on the kind of tool which is being made and the availability of certain fuels, as well as many other factors which must be considered by the tool hardener as applying to his particular problem.

Gas makes a particularly acceptable medium for heating tool steel, owing to its relatively low cost and ease of control. It is also clean and does not as a rule contain any excessive amounts of sulphur and phosphorus, both of which can, under certain

conditions, do considerable harm to the steel which is being heated. (*A typical gas fired furnace is shown in the illustration facing page 17.*)

The oil fired furnace lends itself to many heating operations and can be controlled very accurately where the operator is experienced and uses first-class equipment in the way of burners, etc.

The electric furnace is in many ways ideal for tool steel heating, owing to the automatic control which is possible. A temperature of remarkable uniformity can be maintained without the personal supervision of an operator. The very high initial cost of an electric furnace and the high cost of operation in some localities makes it impossible to use this type of equipment, although there are many applications where it will do remarkably good work at a commercially practical cost.

The open fire still continues to be the means by which many tons of tools and dies are successfully hardened every day. This is particularly true in the case where forging is necessary in order to form the tool, such as in the making of chisels, lathe tools, planer tools, hammers, caulking tools, etc. Provided a deep body of fuel is kept between the tool and the tuyere, successful handling can be done. Where the fire is allowed to become hollow a blast of air coming from the bottom will contain a large excess of oxygen which has not been used up by the fire and which, therefore, could come in contact with the tool and remove the carbon from the surface. We believe that for dies and other delicate tools the open fire is a poor method of heating. It is extremely difficult to get a uniform temperature throughout a piece of steel and the danger of overheating and decarbonizing is very great.

Where the toolmaker is required to turn out tools of good quality, it is poor economy to expect

him to do his work with poor equipment. A little money spent on a first-class, easily controlled furnace will pay large dividends and is an investment every organization should be willing to make. It is not at all unusual to have a loss in one broken die caused by poor equipment that is actually greater than the cost of a first-class furnace.

Production in a shop is largely dependent upon the capacity of the tools and dies used. Every assistance therefore should be given the tool hardener to enable him to turn out a first-class product with a minimum possible loss.

Forging

Tool Steel Cannot Be Forged Like Mild Steel

In forging tool steel there are two things which must be watched carefully, namely, the temperature at which the forging is done and the forging operation itself. The same general practice in heating tool steel should, of course, be used for forging as for hardening, in so far as these remarks cover the slow application of a uniform degree of heat to all parts of the steel. The temperatures used for forging are naturally higher than those used in hardening and a reference list is given showing the approximate forging temperatures for straight carbon tool steels of different carbon contents.

Tool steel can not be forged under the hammer as rapidly as low carbon steels and it is furthermore necessary to maintain a fairly high forging temperature, as working the tool steel at a low heat will produce forging cracks and other undesirable results.

The minimum heat at which tool steel can be forged will, of course, vary in different grades of

steel, but it is a safe rule to say that no tool steel should be forged below a dark cherry red heat.

After the steel has been heated to the proper forging temperature, the forging operation should be carried out as rapidly as possible by the use of light blows, so that the metal will gradually flow into the desired shape by a series of slow motions rather than by sudden large movement produced by heavy blows.

After the forging has been continued to a point where the steel has cooled down to a dark cherry red color, or about 1,275° F., the forging should be stopped and the steel reheated.

It is good practice and considerable time can be saved by using several different heats rather than by trying to rush the forging through in one heat.

A good many blacksmiths are inclined to continue the hammering operation until the steel has lost all heat color. This is bad practice, owing to the fact that small cracks are frequently produced in this way. These cracks are not as a rule noticeable in the forging, but develop during the hardening process and are frequently blamed either on the steel or on the method of hardening.

When heating any piece of tool steel for forging, be quite sure that the proper temperature has penetrated all the way through to the center of the piece. If this is not done the inner portion of the steel, being at a lower heat and therefore harder, will act as a sort of mandril, causing all the forging to be done on the outside of the bar, thus setting up very uneven strains and developing a likelihood of cracking in the subsequent hardening process.

It is not practical to give specific instructions for forging all different kinds of steel, but it may be assumed that the harder a steel is to forge, that is to say, the more it resists the hammer blow, the

more slowly the forging operation should be carried out. For example, high speed steel containing tungsten is very resistant to a hammer, even at a high forging temperature, and this steel should be forged with great care and the shape changed very slowly. On the other hand, a .70 carbon tool steel is quite soft at the forging temperature and can be forged much more rapidly.

After the forging operation has been completed do not allow the forgings to cool off quickly. It is a good practice to follow the forging operation with a simple annealing. This consists of heating the steel to the quenching temperature and then burying in flake mica, dry slacked lime, dry ashes or some other good non-conductor of heat so that the steel will cool slowly.

Annealing

There are two general reasons for annealing tool steel. The first is to put the steel in a condition of maximum softness, so that it can be more readily machined to the desired shape and size. The second purpose is to relieve the strains which have been put in the steel by the rolling or forging operation and to refine the grain so that the steel will respond properly to the subsequent hardening.

In a previous chapter we stated that steel undergoes a certain change when heated to a point beyond its critical temperature and furthermore that the steel would have its maximum hardness if we could retain this changed condition in the steel when at normal or room temperature. We also stated that these changes would reverse themselves in the presence of heat, if given sufficient time, and the annealing process is nothing more or less than one designed to give the steel every

possible chance to make the complete change from the condition produced by heating above the critical temperature, this being brought about by extremely slow cooling.

In annealing steel you raise the temperature to a point above the critical and then reduce the temperature at a very slow rate. This is accomplished most successfully by packing the steel in a container in which all the open space is filled with some such mixture as flake mica, ashes, charcoal, etc. This container is then placed in the furnace and held at a point slightly beyond the critical temperature of the steel for a sufficient length of time to insure complete uniform heat penetrating all the way through to the center of the bars or pieces.

The fire is now shut off and the furnace and its contents allowed to cool down, this operation frequently taking as much as 24 to 48 hours.

In annealing tool steel it is necessary to exclude air as much as possible and it is also advisable to have the minimum amount of scale, inasmuch as both air and scale contain oxygen, which will attack the carbon in the steel and thus produce a decarbonized surface.

Annealing can also be accomplished to a certain extent by heating a piece of tool steel to a point above the critical temperature and then burying the hot steel in some material which is a poor conductor of heat, flake mica being one of the most desirable substances for this purpose. Perfectly dry slacked lime and also dry ashes are used for this purpose. The rate of cooling when using this method is, of course, not as slow nor as uniform and, therefore, the annealing will not be as complete as in the case of box annealing.

It is quite obvious that in the commercial practice of annealing rolled or hammered tool steel

bars it is not practical to remove all the scale from the surface of the steel, nor for that matter is it possible to completely exclude all air. For these reasons there is always a certain amount of oxygen present, either in the form of free oxygen, which is found in the air or the oxide, or scale. This oxygen in the presence of heat and owing to the length of time during which it is kept in contact with the steel, will remove from the surface of the metal a large proportion of the carbon and it is for this reason that all annealed tool steel bars have a certain amount of decarbonized surface or skin. This decarbonized surface is too low in carbon to harden properly and therefore when the outside of the tool is required to be hard it is always necessary to first machine off the outside surface, so as to expose the metal having a high carbon content.

Quenching

The Danger Point in Heat Treating

As we have already explained, the purpose of quenching tool steel is to fix and make permanent in the steel certain changes which have taken place during the heating operation, which changes can not reverse themselves while the steel is at normal room temperature. We have also stated that a reversal of these changes starts to occur as soon as the temperature of the steel has fallen below the critical point, but inasmuch as these changes can not occur instantaneously we can by rapid cooling retain in the steel a certain portion of the changed condition.

It will be clear from these statements that the more rapidly we cool a piece of steel from a temperature above the critical, the greater will be the proportion of the changed condition retained in

the metal. It is, therefore, important to consider the effect of various quenching mediums from the standpoint of their ability to absorb heat rapidly.

Clean water at about 70° F. is the most universally used quenching medium for tool steel and is perhaps the best for the majority of the work where water hardening steels are being used. The temperature of the water has a decided effect on its quenching ability, it being obvious that ice water will cool a tool more rapidly than water which is quite hot. Where extremely rapid cooling is desired, a strong salt solution (brine) can be successfully used and will produce an intensely hard steel. The addition of about 5% of sulphuric acid to water will not change the hardening properties to any noticeable extent, but will produce a very clean white finish, owing to the fact that it will remove most of the scale automatically during the quenching process. It is, of course, necessary to wash the tools immediately after quenching in an acid bath, as otherwise the acid will attack the surface of the metal and produce excessive rust.

There are certain tool steels which are always quenched in oil and where this medium is used it should be remembered that the heavier oils will, as a rule, absorb heat rather more slowly than the lighter oils, so that the maximum hardness is secured by using an oil of a rather light body.

On first thought it would seem that the quenching medium which will cool at the highest rate is the one which should always be used. This, however, is not the case, because while rapid quenching produces the maximum hardness, it also produces the maximum internal strains in the metal and, therefore, the more rapid the cooling the greater the chance of cracking and distortion.

It will be seen from the above that the best method of quenching tool steel is therefore a com-

promise in which the degree of hardness is obtained by the slowest possible rate of cooling, coupled with the minimum danger of cracking and warping. For example, if you find that a certain tool is unnecessarily hard when quenched in cold water, try using water at a slightly higher temperature. If the warm water will give you sufficient hardness, it is the right thing to use, inasmuch as you have reduced the danger of cracking.

The majority of tools do not require cooling to atmospheric or room temperature and, as a general rule, it may be stated that as soon as a tool or die ceases to vibrate in the quenching bath it may be removed and allowed either to cool slowly from this point or be subjected immediately to the drawing or tempering operation.

For example, where a tool is to be water quenched and then drawn back to a temperature of 400° F. in oil, it is good practice to have the oil bath already heated to 400° before the quenching operation is started. The tool will then be quenched in water until vibration has ceased and it will be immediately transferred to the oil bath, where it will be allowed to remain for a sufficient length of time, after which it is allowed to cool off slowly to atmospheric temperature.

If uniform results are to be obtained in quenching, all conditions must be held as nearly uniform as possible. It is, therefore, necessary that the quenching bath be kept at a fairly constant temperature. When a piece of steel is quenched in a tank of water the temperature of the water is raised, this increase continuing as long as the quenching operation is continued, until the water may actually reach the boiling point.

From the preceding remarks our readers will understand that the last tool quenched in this hot water will not have the same hardness as the first

tool quenched, so that where uniform hardness is to be obtained it is necessary to provide some method of keeping the quenching water at a reasonably uniform temperature.

In the case of water quenching it is usual to keep the quenching bath cool by allowing fresh water to run in at the bottom of the tank and to have an overflow provided at the top so that the heated water can flow away.

In the case of oil quenching, the oil, of course, can not be wasted and, therefore, where a number of pieces are to be quenched the hot oil can be circulated through pipes which are surrounded by cold water or the whole quenching tank can be surrounded by a water jacket in which cold water is kept circulating.

In quenching tool steel the operator should endeavor, as far as possible, to obtain a uniform hardness throughout the entire piece, except in the case of certain tools where it is the desire to only harden one portion, such as in chisels, hammers, etc. With this idea in mind the heavier portion of a tool or die should enter the quenching medium first, inasmuch as the heavy part of the tool will retain its heat longer and will, therefore, have a tendency to cool slower and to attain a less degree of hardness than the thin or light portions.

Whenever a tool or die is quenched it should be kept in motion. If this is not done, steam will accumulate at different points and hold the quenching medium away from the surface of the metal, thus allowing these points to cool more slowly than the rest of the tool and producing soft spots.

In general when quenching tool steel remember that you are taking a piece of material which is in a soft and plastic condition and that you are suddenly changing it to an extremely hard and brittle condition, and accompanied by a great change

in volume, owing to the shrinkage. You will readily understand that there is every chance in the world of fracturing tool steel on account of the rapid changes in temperature and shape which it must undergo. All possible precaution should be taken to see that the steel is given every possible chance of attaining the desired hardness with the least drastic treatment which can be used.

Always use the lowest temperature which will give you the desired result and always use the slowest method of quenching which will produce the necessary hardness. Nothing is gained by hardening a tool to an extreme degree of hardness when this tool will have to be drawn or tempered to a very much lower hardness before being used. In a case of this kind it would be much better and much safer to harden the tool to a point not far above that ultimately required.

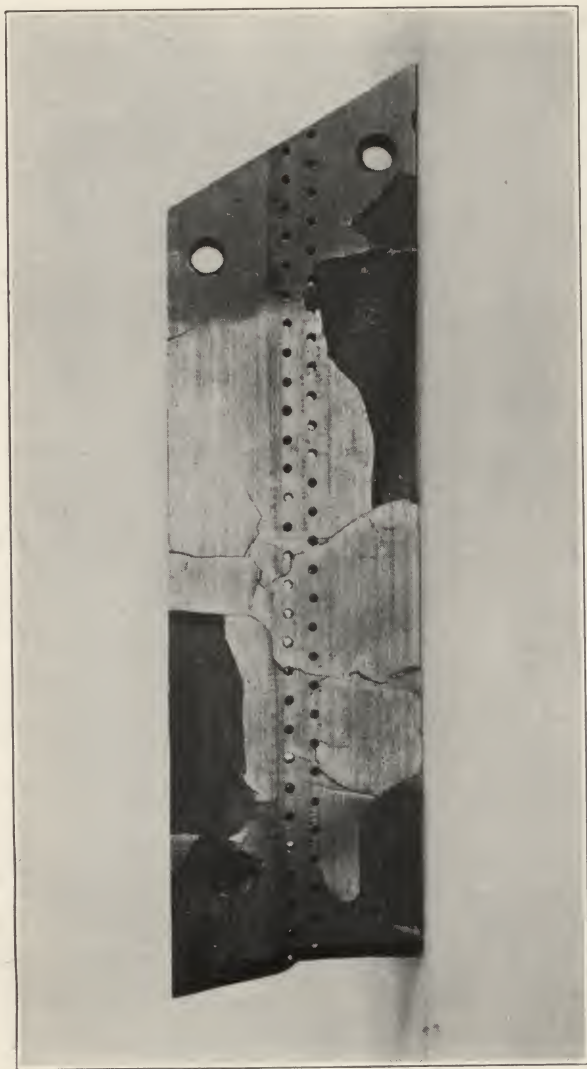
Drawing (Tempering)

We have already explained what happens when a piece of tool steel is hardened and the reader will, therefore, now understand that tool steel in the hardened condition is more or less like a clock spring which has been wound up as far as possible.

Tool steel in the fully hardened condition is not sufficiently tough and strong for the majority of uses and it is, therefore, necessary to remove a portion of the hardness, which is equivalent to partly unwinding the clock spring.

Hardened tool steel will start to return to its natural condition only in the presence of heat and the amount of change or return is, up to a certain point, proportional to the temperature.

With the majority of tool steels the change in hardness will start at about 300° F., the amount of change increasing until the temperature has been



A hardened tool steel die which has been ruined by too heavy grinding. Note that the edges of the cracks are raised, giving the appearance of having been pulled up. (See page 40.)



Tapping a five-ton electric furnace, used in making tool steel. The metal is melted and refined in this furnace and when its analysis has been brought up to standard and tested, the furnace is tilted and the molten steel is poured into the waiting ladle. It is then ready to cast into ingots.

raised to the critical point of the steel, at which point the change is practically complete, so that the steel will have returned completely to its original condition.

It is apparent from the above that the tempering operation consists of the application of relatively low heats. This may be accomplished by one of several methods, such as immersion in oil, sand, molten lead, molten salt baths, etc., and also by direct heating in a furnace.

The hot oil bath can be successfully used up to temperatures of about 550° F., this being the approximate maximum limit for oil, owing to the fact that it will start to burn if the temperature is raised much beyond this point. Oil offers a very desirable means of tempering up to its maximum heat capacity on account of its low expense, freedom from any tendency to scale the steel, and also because its temperature can be readily measured by the direct insertion of a high temperature thermometer. It is seldom that carbon tool steels are drawn beyond 550° F., so that oil will, as a rule, take care of the ordinary job.

A mixture of two portions of potassium and three portions of sodium nitrate will have a melting point in the neighborhood of 500° F., this mixture making a very good molten bath for a temperature up to about 1,000° F.

Lead melts at approximately 700° F. and can be used with success up to quite a high temperature, although it is advisable to keep some powdered charcoal on top of the bath so as to prevent oxidation of the lead itself.

In using any hot bath it must be remembered that these hot liquids impart their heat very rapidly to the tool and if, therefore, a fairly high temperature is used it is advisable to preheat the tool before immersion.

There is another method used in drawing the temper of tools which have to be harder at one point than another. The chisel, hammer, caulking tool and center punch are examples of this class of tool. Tempering for these tools is frequently accomplished by first heating the cutting edge and some of the metal behind to the hardening temperature. A little more than the cutting edge of the tool is then quenched to maximum hardness and rapidly polished with a piece of emery cloth. The heat remaining in the body of the tool will travel by conduction to the portion which has been hardened and at the right time the whole tool can be quenched a second time, thus preventing the tempering or drawing operation from going too far. The drawing temperature of the cutting edge is judged, when using such a method, by the color produced on the polished portion of the tool by oxidation.

Different temperatures produce different colors due to oxidation, and these colors are used to judge the temperature to which the tool edge has been heated.

On page 87 of this book a table will be found listing the various temper colors and the approximate corresponding temperatures.

In all drawing operations it is necessary to consider the time element. It is a well known fact that a tool drawn to 400° F. for ten minutes will not be as soft or ductile as a similar tool which has been held at 400° F. for thirty minutes. From this it will be seen that when using a tempering bath, such as hot oil or molten lead, the length of time which the tools are allowed to remain in the bath must be noted and duplicated each time, if uniform results are to be obtained.

The tempering operation should always be carried out as promptly as possible after the harden-

ing operation. The reason for this is that tempering not only gives the desired hardness to the tool, but also relieves most of the internal strain which has been imposed by the hardening process.

Wherever possible, it is desirable to transfer the hardened tools directly from the quenching tank to the drawing bath. By so doing, the tools never cool off entirely and much danger of cracking is avoided.

Testing Tool Steel

It is very important that anyone attempting to harden a tool should have an idea as to how he may test his work before the tool is actually put into operation. In some cases a test will show that a tool has been improperly hardened, and if this can be determined before the steel is put into service it will give the tool hardener an opportunity to reharden the tool properly.

In working with any new or unfamiliar tool steel, the hardener should always cut off a small test piece with which he can experiment in order to determine the proper hardening temperature before attempting to harden a die or tool, the making of which has involved considerable expense.

The lowest temperature at which any tool steel will harden is the best temperature to use for that particular steel and, therefore, valuable information can be gained by cutting a small disc or section from the end of the bar and determining by experiment the best hardening temperature to be used, so as to produce the necessary hardness together with the finest possible grain. This test can also be carried through to determine the right temperature to be used with any particular steel and all this information put together is very val-

uable when it comes to hardening the tool or die itself.

The test pieces can be tried for hardness with a file, or if available, with a scleroscope, and it should always be fractured to afford an opportunity for examination of the grain size.

In making such tests it is well to start with the hardening temperature which the operator considers a little bit too low. If test indicates that the temperature is actually too low, gradually increasing temperatures can be used until the operator has determined the minimum temperature which will successfully produce the hardness required.

In conducting hardening tests on sample pieces it should be remembered that a small sample will harden satisfactorily at a lower temperature than a larger piece of the same steel. This is because the smaller section will lose its heat much more rapidly when placed in the quenching medium.

Heat Measurement

All operations in connection with forging, hardening, tempering and annealing of tool steel involve the use of heat and it is therefore necessary to have some means of determining various degrees of heat so that the correct treatment can be applied and uniform results secured.

In measuring temperature over about 650° F. the thermometer is not applicable and it is, therefore, necessary to use the thermo-couple pyrometer or the optical pyrometer.

Very briefly, the principle of the thermoelectric couple is as follows: When two pieces of metal of different composition are joined together at both ends so as to form a complete electric circuit, a flow of current is produced when the two junctions or joints are at different temperatures.

Provided that the wires are of exactly uniform composition throughout, the difference in electromotive force, or voltage, is directly proportional to the increase in temperature, and therefore, if a very delicate voltmeter or galvanometer be placed in the circuit, a reading can be obtained which will indicate the difference in temperature of the two junctions.

Selection of pyrometer equipment must be governed by such factors as the permissible original cost and also shop conditions and kind of work which will be undertaken. These several matters having been determined, the pyrometer equipment installation should be turned over to one of the recognized and dependable pyrometer manufacturers, all details being left to their experience and co-operation.

In connection with this matter, it may be well to emphasize the desirability of recording pyrometers. These instruments are provided with a moving chart, on which a line is automatically drawn indicating the furnace temperature at all times. Such a recorder can be kept in a locked box, thereby providing evidence as to just how accurately the furnace operator has followed his instructions in reference to temperature and time.

Whatever system is installed, it must be remembered that the pyrometer is essentially a delicate instrument, and the voltages and currents handled are necessarily extremely small. For these reasons it is essential that the couples be properly protected from furnace gas action and that they be handled with care. All *contacts* must be kept *scrupulously* clean and the indicating and recording instruments so placed that they are free from excessive vibration and jar, such as may be produced by steam hammers or other heavy machines. Pyrometers must be accurately checked at fairly

frequent intervals, this being best handled by the service departments of the various pyrometer manufacturers.

If the pyrometer equipment is given adequate care and attention, readings of remarkable accuracy can be obtained, but, on the other hand, if not properly cared for, inaccuracies are bound to develop and trouble with heat treatment will surely follow.

Many a good piece of tool steel has been spoiled by the operator failing to notice the fact that the thermo-couple was much hotter, or perhaps much colder, than the steel which he was treating.

The optical pyrometer is an instrument which is usually portable and reasonably accurate. There are a number of different types, but as a rule these instruments consist of a small telescope, which is focused directly on the heated piece of steel. The color of the heated steel is then compared to a standard color which appears alongside of it in the instrument and which color can be varied by an adjustment of the apparatus. The amount of adjustment necessary to make the two colors identical is the means by which the temperature of the steel is determined.

The disadvantage of an optical pyrometer is that it does not give a constant indication of temperature, nor is any permanent record available from its readings. For a small shop where the product is of an intermittent character, the optical pyrometer, we believe, is a very useful and serviceable apparatus.

When tool steel is being drawn or tempered, it is common practice to depend on the film of oxide, which is produced on a clean surface of steel by the action of heat. The color of this oxide varies with the temperature and with certain limitations

is a fairly accurate indication of the temperature of the steel itself.

A list is given showing the various temper colors and the supposed corresponding temperatures.

In using these different colors it must be remembered that the color referred to for a certain temperature is the first color which the steel assumes at any constant temperature. Experiment will show that a temperature of about 450° F. will first produce a light straw color on the surface of the steel, but if the steel is held at this temperature for a sufficient length of time this light straw color will change to a brown and later on to a purple. Some hardeners claim if a purple color is obtained it makes no difference whether this is obtained by rapid heating and prompt cooling at about 540° F. or whether it is obtained by a lower temperature over a longer period of time. This particular question is problematical and we will not attempt to pass on the soundness of the theory.

There is another method of determining the correct hardening temperature of straight carbon tool steel, not for the purpose of determining temperature at all, but with the idea of determining the correct hardening point for any particular kind of steel. It is a recognized fact that tool steel is magnetic at ordinary room temperature and also that the degree to which it will attract a permanent magnet decreases as the temperature is raised, until at a point a little above the critical temperature it becomes entirely non-magnetic. This non-magnetic point is extremely close to the ideal hardening temperature, and if, therefore, the steel is tested from time to time with a small magnet during the heating operation, it may with safety be withdrawn and quenched as soon as the steel has ceased to be magnetic. This magnetic test is best carried out by using a short straight

magnet which is pivoted in the center and free to swing. This magnet is attached to the end of a long brass rod and can be inserted in the furnace, so that any slight attraction on the part of the tool will cause a deflection of the magnet itself.

The most popular form of heat measurement is, of course, the old-fashioned human eye, and while under certain conditions remarkably good results are obtained, we can not pretend to give you any information on the operation of this particular instrument.

You will find a list given in this book showing various temperatures and the names commonly attributed to them, such as cherry red, salmon color, yellow, etc. Just what temperatures do correspond to the different colors will all depend on the individual interpretation of any particular color. No two men will agree on just what a light yellow heat is, nor will the same man judge his color in the same way in a well lighted room in the daytime and the same room at night.

Good tool hardeners have, by years of experience, worked out their own ideas of eye temperature measurement and we would not attempt to instruct anyone in this art, inasmuch as it is an entirely personal ability and not one which can be taught.

Grinding

Grinding is, of course, not a part of heat treatment, but owing to the fact that a large number of perfectly good dies and tools are spoiled by improper grinding we venture to mention the subject.

As far as possible, do your heavy grinding before the tool or die is hardened. A piece of annealed tool steel can be ground rapidly without harmful

effect, but in grinding hardened tool steel great care must be exercised.

Grinding always produces heat, and if the grinding is carried on a little too heavily the cutting edge of the tool may be heated to a point where it is allowed to go back to its natural condition to such an extent that it is rendered too soft for use.

Another difficulty produced by heavy grinding is the development of a large number of surface cracks on a piece of hardened steel, this being particularly prevalent in the grinding of a large flat surface on an automatic grinder. When a grinding wheel is forced onto the surface of a piece of hardened steel, the temperature at the point of contact can be raised to a very high degree. This increase in temperature results in a sudden expansion of a small portion of the steel at one point and, inasmuch as the surrounding steel is quite hard and brittle, surface cracks are the immediate result. These cracks usually appear as very fine lines running in all directions and the fractured edges often seem to be raised above the rest of the metallic surface. (*See illustration facing page 32.*)

When grinding tool steel use a soft, coarse wheel. Keep it clean and grind with a light cut and slow feed.

When a tool or die has been surface-cracked by rapid grinding, do not attempt to grind these cracks out, as this is almost impossible. Little cracks will continue down into the body of the steel just as fast as you grind off the surface. There is only one sure way to get rid of these surface cracks and that is to anneal the steel, machine off the surface and reharden. This is an expensive operation and, therefore, money and time can be saved by very slow and careful grinding.

General Remarks

Every tool hardener knows that the finer the grain structure of a piece of hardened tool steel the better will the tool or die operate. Therefore the hardening method which will produce the smallest grain size is the one which should be used.

The fracture of a piece of annealed tool steel will indicate the grain size and the application of heat will produce a change in this grain size which is very noticeable to the naked eye. As the temperature of the annealed tool steel is increased the grain size will continue to become smaller until a point slightly above the critical temperature has been reached. A further increase in temperature will produce an increase in the size of the granular structure up to a point where the fractured steel will have the appearance of a lump of sugar.

We already know that in order to harden tool steel it is necessary to heat it to a point slightly beyond the critical temperature and it will now be evident that the finest grain will be obtained by using a hardening temperature as little in excess of the critical temperature as possible.

The grain size of hardened tool steel can be advantageously used as a means of determining the best hardening temperature for some brand of tool steel with which the tool hardener is not familiar. Five or six pieces of the same kind of steel hardened at different temperatures and fractured will enable the tool hardener to determine the best heat to use in hardening that particular kind of steel. If this procedure is followed out when a new steel is being used a lot of time and money can be saved.

As the grain size of hardened tool steel is dependent on the hardening temperature, the quenching

tank should be placed near the heating furnace or fire, otherwise a considerable drop in temperature will take place during the period of transfer from the furnace to the quenching medium. Where this happens it will be necessary to heat the steel to an excessive temperature to compensate for the loss of heat during transfer to the quenching tank and the grain size of the steel will be governed by the temperature to which it was heated in the furnace and not by the temperature at which it was quenched.

All tool steel should be quenched on a rising or stationary temperature. Nothing is gained by overheating a piece of steel and then allowing it to cool down before quenching, except perhaps that the danger of cracking may be slightly reduced.

It is sometimes desirable to harden only a part of a tool, this being accomplished by only quenching that portion which it is desired to harden. When carrying out such an operation, care should be used to keep the steel in motion in order to eliminate the possibility of developing a sharp line of demarcation between the hardened and unhardened portions of the tool. Where the steel is kept in motion a gradual tapering off in hardness will be produced and the danger of cracking is thereby reduced to a minimum.

The degree of hardness, as we have previously pointed out, depends upon the rate of cooling, and it is, therefore, necessary to consider the effect of the surface of the steel in connection with this matter.

In quenching a piece of tool steel having a very rough machined surface, it is found that a film of steam will adhere to the surface of the steel, thus lowering the efficiency of the quenching medium and preventing the attainment of full hardness. In order to secure a maximum hardness in tool steel the sur-

face should be quite smooth, having a finish similar to that produced by a fine-cut file.

It is, of course, desirable to have the same temperature in all parts of a piece of tool steel which is being hardened. Theoretically this condition can be obtained by using a furnace which is at the same temperature in all different places. Such a furnace is a hard thing to find, and therefore when the tool or die is being heated it should be moved around in such a way as to overcome any inequalities in temperature existing in the different parts of the furnace.

As a rule, a non-shrinking tool steel is used where it is desired to harden a tool or die with a minimum shrinkage or warping, inasmuch as these steels have much less tendency to change shape than water hardening steels. It is not, however, always possible to use an oil hardening steel and special precautions are taken to produce the best possible result from the material available.

When tool steel is annealed, the forging, hammering and rolling strains are reduced as much as possible, but it must be remembered that this condition can not be fulfilled entirely. When a piece of annealed steel is machined and thus radically changed in shape, certain new strains are set up and these strains are apt to produce warping and shrinkage during the hardening process.

The best way to reduce this danger to a minimum is to give the tool an anneal between rough machining and finished machining operations.

There is one point which tool and die makers should bear in mind as much as possible, that is, the desirability of so designing their dies and tools that standard size bars can be used in their manufacture. Tool steel is an expensive material, and

owing to the difficulty with which even thoroughly annealed tool steel is machined, a lot of money can be wasted when it becomes necessary to remove a large amount by machine work. If the toolmaker will consult a tool steel stock list before designing his die he can frequently effect a considerable saving by figuring on the use of a standard warehouse size. Special sizes can, of course, be produced by any mill, but where the quantities involved are not large, considerable delay is occasioned and no particularly advantageous result is obtained.

We venture to point out to every shop superintendent the economy of providing the toolmaker with first-class equipment for hardening and tempering, as well as first-class steel. It is neither fair to the tool hardener nor to the shop to ask that dies and other tools be hardened with inefficient equipment. A good furnace to provide accurate temperature control and a good quenching tank with plenty of first-class quenching medium does not represent a very large investment, but the saving by increased production and the reduction in loss of expensive tools and dies will be a great benefit to all parties concerned.

Whenever the purchase of tool hardening equipment is contemplated it would be well to present your various hardening problems to several reputable equipment manufacturers. These people have in all probability met and solved similar problems in other shops and the experience which they have gained will be valuable to you and constitutes a service to which you are entitled and of which you should avail yourself as much as possible. Very often a furnace manufacturer can make very valuable suggestions which are the result of extensive experiment and research, and inasmuch as this service is entirely free it is something which no shop superintendent can afford to ignore.

Quite frequently it is necessary to straighten a piece of tool steel after hardening in order to correct warpage. Where this is to be done, the straightening should be carried out immediately after drawing and while the steel is still hot. Hardened tool steel before it is cooled off is fairly pliable and can be straightened if care and discretion are used in this operation.

We would like to caution tool steel users against the practice of cutting tool steel bars by nicking and breaking. This practice, while saving considerable time, is dangerous, inasmuch as small cracks are frequently started in such a way that they develop and cause damage to the tool in the subsequent hardening operation.

Important

All ANNEALED tool steel must be ordered sufficiently oversize to allow complete removal of outer surface which has been decarbonized as a result of the annealing process. If this is not done, the surface of the steel will not harden.

(See pages 27 and 28.)

Ryolite Tool Steel

ALL tool steels sold by Joseph T. Ryerson & Son, Inc., are offered to our customers under the trade name of "Ryolite." The purpose of this trade name is to distinguish our steels from those offered by our competitors and also as a reminder that the reputation and integrity of the Ryerson organization is behind the steels and will back them to the limit when they are properly and fairly used.

All Ryolite tool steel is subject to a double inspection. First, the normal inspection which it is given at the mill where it is made and, second, the inspection which it receives when it comes into our warehouse.

All Ryolite steels are absolutely guaranteed against defects in either material or workmanship and are also guaranteed to do the work for which they are sold, provided, of course, that our customers give them the proper treatment.

We can not assume liability for labor or damages resulting from the failure of any of our steels. We would be glad to assume such responsibility were it not for the fact that the labor cost entering into a tool steel failure is usually many times greater than the gross sale value of the steel itself.

For example, a piece of die steel costing \$5.00 may be made into a die in a customer's shop on which \$100.00 is spent in labor. Should this die crack during the hardening operation it is obviously unfair that the seller of the steel should be asked to assume the responsibility of \$100.00 on the gross sale of \$5.00.

We naturally want our customers to get the right steel for their work. Should you have any questions regarding the selection of the proper

steel or its heat treatment, write us and we shall be glad to give you the benefit of our experience.

Identification

All Ryolite tool steel shipped from our warehouse stock is painted over the entire length of the bar with a distinguishing paint. This system of distinguishing colors is used for the mutual protection of the buyer and seller. We believe that you will find it convenient to have each bar of Ryolite Steel which you are holding in your rack automatically and permanently marked in an unmistakable way over its entire length. The standard colors used on Ryolite tool steels are as follows:

RYOLITE DIAMOND "B" CARBON TOOL STEEL.....	<i>Brick Red</i>
RYOLITE X CARBON TOOL STEEL.....	<i>Yellow</i>
RYOLITE XX CARBON TOOL STEEL.....	<i>Green</i>
RYOLITE XXX CARBON TOOL STEEL.....	<i>White</i>
RYOLITE B-F-D OIL HARDENING TOOL STEEL.....	<i>Aluminum</i>
RYOLITE 4-POINT CHISEL STEEL... ..	<i>Bright Red</i>
RYOLITE HIGH SPEED STEEL (ANNEALED).....	<i>Blue</i>

What Steel to Use

Some tools and the grade of Ryolite Steel recommended for making them.

This list is merely for our customers' general guidance. There are many cases where particular conditions require the use of some grade other than that recommended here.

Arbors (Machine Tool).....	Ryolite X or some Alloy Steel
Ball Races and Cones.....	Ryolite X—BFD—Alloy Steel
Bits (Channeler).....	Ryolite X—Diamond B
Broaches.....	BFD
Bushings.....	Ryolite X—BFD
Center Punches.....	Ryolite X—Diamond B
Chisels (Machine Shop).....	Ryolite 4 point
Chisels (Pneumatic).....	Ryolite 4 point
Chisels (Blacksmith).....	Ryolite X—Diamond B
Caulking Tools.....	Ryolite X
Claw Bars.....	Diamond B
Cutters, Milling.....	High Speed—BFD—Ryolite XXX
Brass Cutting Tools.....	BFD—Ryolite XXX
Cutting off tools—beveled.....	Mill Treated High Speed
Dies (Threading).....	High Speed—Ryolite XXX



A corner of one of the Ryerson tool steel warehouses. Different grades of steel are kept in separate bins and are distinguished from each other by the color painted the entire length of each bar. Over 700 different kinds and sizes are stocked in this tool steel warehouse, with quantities of each to meet any ordinary requirement.



Painting each bar with an identifying color before it is placed in stock. The bars on the truck have just arrived from the mill—note the heat number, 2223, the size, 3", and the grade, X. The identification color is painted on the entire length of the bar, so that your tool maker will know what kind of steel it is, no matter how small a piece he may have

T O O L S T E E L I N S T O C K

Dies (Blanking).....	BFD—sometimes High Speed—Ryolite XXX
Dies (Forming).....	BFD—Ryolite XXX
Dies (Drawing).....	BFD—Ryolite XXX—sometimes High Speed
Dies (Drop Forging).....	Special analysis die blocks
Drills for Metal.....	Ryolite XXX—Drill Rod
Drills for Stone.....	Ryolite X—Diamond B
Engravers' Tools.....	Ryolite XXX
Flatters (Blacksmith).....	Ryolite X—Diamond B
Fullers (Blacksmith).....	Ryolite X—Diamond B
Gauges.....	Ryolite BFD
Hammers.....	Ryolite X—Diamond B
Hobs.....	Ryolite BFD—Ryolite XXX—High Speed
Lathe Centers.....	Ryolite X—XXX
Lathe Tools (Metal Working).....	High Speed—Ryolite XXX
Lathe Tools (Wood Working).....	Ryolite BFD—Ryolite XXX
Mills—End.....	High Speed—BFD
Pins—Drift.....	Ryolite X—Diamond B—sometimes Alloy Steel
Pinch Bars.....	Diamond B
Planer Tools (Metal Working).....	High Speed
Planer Tools (Stone Working).....	Ryolite XXX—High Speed
Punches (Blanking).....	Ryolite BFD—Ryolite XXX
Punches (Hand).....	Ryolite X
Punches (Backing Out).....	Ryolite X—Diamond B
Reamers.....	Ryolite BFD—Ryolite XXX—High Speed
Rolls.....	Ryolite XX—Ryolite BFD
Shear Blades.....	Ryolite XX—Ryolite XXX—Ryolite BFD
Scrapers (for wood).....	Ryolite Tool Steel Sheets
Screw Drivers.....	Ryolite X—Diamond B—sometimes Alloy Steel
Sledges.....	Ryolite X—Diamond B
Swages (Blacksmith).....	Ryolite X—Diamond B
Taps (Hand).....	Ryolite XXX—BFD
Tool Holder Bits.....	Ryolite T. H. Bits
Teeth (Scarifier).....	Ryolite Diamond B
Thread Rolling Dies.....	Ryolite BFD—Ryolite XXX—High Speed
Wedges (Stone).....	Diamond B
Wrenches.....	Ryolite Diamond B—sometimes Alloy Steel

Important

All ANNEALED tool steel must be ordered sufficiently oversize to allow complete removal of outer surface which has been decarbonized as a result of the annealing process. If this is not done, the surface of the steel will not harden.

(See Pages 27 and 28)

Ryolite Diamond "B" Carbon Tool Steel

Identification Color—Brick Red

This is a special analysis straight carbon tool steel for use in cases where a steel is required having toughness and strength rather than a very keen cutting edge. The carbon content is sufficiently low to make a strong tool capable of standing heavy pounding and at the same time sufficiently high to give a reasonably hard edge.

HEAT TREATMENT:

Forge about 1650° (salmon color).

Harden in water at 1390° to 1450° (medium cherry red).

Anneal at 1400° to 1425°.

SUITABLE FOR:

Hammers	Sledges
Hand Chisels	Tongs
Bucket Teeth	Wrenches
Butt Hooks	Track Tools
Pick Points	Rock Drills
Flatters	Pinch Bars
Concrete Points	Furnace Bars
Crowbars	Drift Pins
Wrecking Bars	Star Drills
Fullers	Scarifier Teeth
Hardies	Coal Mining Tools
Hooks	Boiler Shop Tools
Mauls	Smiths' Tools
Wedges	

CARRIED IN STOCK:

Octagons (not annealed). Sizes from $\frac{1}{4}$ up to $1\frac{3}{4}$ inches.

Squares (not annealed). Sizes from 1 inch up to 2 inches.

For complete list of all sizes carried in stock, see current issue of the Ryerson Journal and Stock List or refer to Stock Supplement in back of this book.

Important

All ANNEALED tool steel must be ordered sufficiently oversize to allow complete removal of outer surface which has been decarbonized as a result of the annealing process. If this is not done, the surface of the steel will not harden.

(See pages 27 and 28.)

Ryolite X Water Hardening Carbon Tool Steel

Identification Color—Yellow

This is the quality of steel ordinarily known as standard or common grade. Ryolite X is a first-class product of a higher carbon content than Diamond "B," made by a better method and of higher grade base material. This steel will take a hard temper and will hold a good cutting edge on certain classes of tools.

HEAT TREATMENT:

Forge about 1625° (bright cherry red).

Harden in water at 1375° to 1450° (medium cherry red).

Anneal at 1425° (low to medium cherry red).

SUITABLE FOR:

Hand Tools	Hooks
Blacksmith Tools	Boiler Shop Tools
Beading Tools	Cant Hooks
Center Punches	Arbors
Bushings	Drill Bushings
Hammers	Punches
Nail Sets	Fullers
Hammer Dies	Flatters
Drift Pins	Drills
Star Drills	Chisels (Hand)
Clinch Jaws	

CARRIED IN STOCK:

Rounds (annealed). Sizes from $\frac{1}{4}$ up to 6 inches.

Squares (annealed). Sizes from $\frac{1}{4}$ up to 4 inches.

Octagons (not annealed). Sizes from $\frac{1}{4}$ up to $1\frac{1}{2}$ inches.

Hexagons (not annealed). Sizes from $\frac{3}{8}$ up to $1\frac{1}{2}$ inches.

For complete list of all sizes carried in stock, see current issue of the Ryerson Journal and Stock List or refer to Stock Supplement in back of this book.

Ryolite XX Water Hardening Carbon Tool Steel

Identification Color—Green

This quality is ordinarily known as EXTRA GRADE tool steel but differs from competitive products in that it contains vanadium. This vanadium does two things. Firstly, it makes the steel cleaner and therefore more uniform and it also broadens the hardening range so that even if Ryolite XX is overheated, the grain size will not enlarge as much as it will in steels containing no vanadium. Ryolite XX Carbon Tool Steel combines a really high quality product with a moderate price. It is intended primarily for use where it is necessary to produce a good tool and where the purpose for which the tool is to be used does not warrant the purchase of an expensive steel.

The combination of reasonable price and quality render this grade particularly applicable to general shop use. Ryolite XX will take a hard temper, will machine quite freely and can be depended upon for uniform and satisfactory service.

HEAT TREATMENT:

Forge at about 1600° (bright cherry red).

Harden in water at 1375° to 1450° (low to medium cherry red).

Anneal at 1425° (low to medium cherry red).

SUITABLE FOR:

Punches	Hammer Dies
Dies	Drills
Chisels (Hand)	Nail Sets
Shear Blades	Paper Cutting Knives
Forming Tools	Lathe Centers
Jig Bushings	Metal Working Rolls
Woodworking Knives	Countersinks
Stone Cutters' Chisels	Forming Dies
Lathe Turning Tools	Hot Shear Blades
Trimmer Dies	Rotary Shears

CARRIED IN STOCK:

Flats (annealed). Sizes from $\frac{1}{8}$ up to 3 inches thick and $\frac{3}{8}$ up to 10 inches wide.

Squares (annealed). Sizes from $\frac{1}{4}$ up to 6 inches.

Rounds (annealed). Sizes from $\frac{1}{4}$ up to 6 inches.

Octagons (not annealed). Sizes from $\frac{1}{4}$ up to $1\frac{1}{2}$ inches.

For complete list of all sizes carried in stock, see current issue of the Ryerson Journal and Stock List or refer to Stock Supplement in back of this book.

Ryolite XXX Water Hardening Tool Steel

Identification Color—White

We offer this steel as the highest grade water hardening tool steel which can be produced. Maximum care in manufacture and the best procurable raw material combined, produce a product of the finest possible quality.

It differs from competitive products in that it contains vanadium. This vanadium does two things. It makes the steel cleaner and therefore more uniform and it also broadens the hardening range. Even when Ryolite XXX is overheated, the grain size does not enlarge as much as it does in steels containing no vanadium.

Where the design of the tool is such that a water hardening steel can be used, and where the maximum hardness and durability are to be obtained, we recommend the use of this grade. Ryolite XXX, owing to its analysis and method of manufacture, is particularly adapted to resist shock and vibration.

HEAT TREATMENT:

Forge at about 1600° (bright red).

Harden in water at 1375° to 1425° (medium cherry red).

Anneal at 1425° (medium cherry red).

SUITABLE FOR:

Dies (Blanking and
Forming)
Cold Heading Dies
Stone Planer Tools
Woodworking Tools
Lathe Turning Tools
Pneumatic Tools
Roll Thread Dies
Punches
Nail Dies
Rivet Sets

Drills
Reamers
Taps
Drawing Dies
Milling Cutters
Embossing Dies
Metal Turning Tools
Shock Tools of all kinds.
Silversmiths' Dies
Spinning Tools

CARRIED IN STOCK:

Flats (annealed). Sizes from $\frac{1}{8}$ up to 2 inches thick and from $\frac{3}{8}$ up to 8 inches wide.

Rounds (annealed). Sizes from $\frac{1}{4}$ up to 7 inches.

Squares (annealed). Sizes from $\frac{1}{4}$ up to 6 inches.

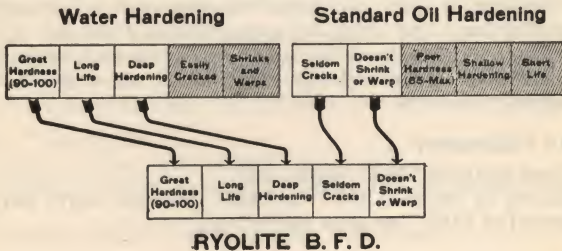
For complete list of all sizes carried in stock, see current issue of the Ryerson Journal and Stock List or refer to Stock Supplement in back of this book.

Ryolite B-F-D Oil Hardening Tool Steel

Identification Color—Aluminum

There are many dies and other tools which are of such an intricate character and the making of which involves so much expense that the tool hardener can not take the chance of cracking and warping, which always accompanies the use of a water hardening steel.

In the past, toolmakers have avoided the use of oil hardening steel wherever possible, inasmuch as the ordinary oil hardening steel, while being free from the danger of cracking and warping, does not produce as good a cutting tool as a water hardening steel.



In Ryolite B-F-D we offer a steel which combines the hardness and cutting quality of our Ryolite XXX with freedom from danger of warping and cracking. For these reasons, we suggest the use of Ryolite B-F-D as a matter of insurance against the loss of labor, which occurs when an expensive tool warps or cracks during the hardening process.

Ryolite B-F-D, when properly annealed, machines quite readily and has an extremely wide hardening range, so that the danger of overheating is very slight. This is a great advantage in the small shop which is not equipped with accurate heat measuring devices.

The grain of hardened B-F-D is extremely fine and velvety in appearance, looking much like high speed steel. The hardness will penetrate to a great depth, thus enabling the user to regrind the die a number of times before it is necessary to reharden.

Ryolite B-F-D is a very dense steel and should, therefore, be heated more slowly than our other grades, inasmuch as the heat does not penetrate as rapidly throughout the piece.

When quenching Ryolite B-F-D use any good, clean quenching oil and draw the temper immediately after hardening and before the steel has had time to cool off to room temperature.

HEAT TREATMENT:

Forge at about 1700° to 1900° (orange to light yellow). Do not forge this steel cold.

Harden in oil 1550° to 1650° (bright red to salmon). On large sections, a temperature of 1725° can be used without damaging this steel.

Anneal at 1500° (a long anneal and extremely slow cooling are necessary for this steel).

SUITABLE FOR:

Forming Dies	Ring Gauges
Blanking Dies	Drill Bushings
Cold Heading Dies	Reamers
Drawing Dies	Milling Cutters
Embossing Dies	Broaches
Wire Working Dies	Drills and Taps
Lathe Centers	Punches
Threading Dies	Ball Bearing Races
Plug Gauges	Brass Turning Tools

CARRIED IN STOCK:

Flats (annealed). Sizes from $\frac{1}{8}$ up to 2 inches thick and from $\frac{3}{8}$ up to 8 inches wide.

Rounds (annealed). Sizes from $\frac{1}{4}$ up to 7 inches.

Squares (annealed). Sizes from $\frac{1}{4}$ up to 6 inches.

For complete list of all sizes carried in stock, see current issue of the Ryerson Journal and Stock List or refer to Stock Supplement in back of this book.

Ryolite Tool Steel Sheets

(Also known as Spring Steel Sheets),

These sheets are used for many purposes, such as the making of small slitting saws, special knives, small springs, shims, etc.

Owing to the thin section of these sheets, while made of a water hardening tool steel, they will in the majority of cases harden to a sufficient degree in oil. Ryolite tool steel sheets are semi-annealed, so that while they have a reasonable degree of springiness, they are sufficiently soft to drill and punch without further annealing.

CARRIED IN STOCK:

Size, 18 x 72 inches. Thicknesses, $\frac{3}{16}$ inch to No. 30 B. W. gauge.

Ryolite 4-Point Chisel Steel

Identification Color—Bright Red

We have long realized the desirability of producing a steel for chisels which could be forged and hardened in the same way as a straight carbon steel, but which would be more resistant to shock and would give better all around service. It is quite easy to produce an alloy chisel steel that will stand up better than a straight carbon water hardening steel, but such alloys usually require special treatment.

In our Ryolite 4-Point Chisel Steel we are offering you a material *which is forged and hardened in exactly the same manner as a straight carbon chisel steel, but which will produce materially better results in the way of cutting qualities and ability to resist shock and vibration.*

HEAT TREATMENT:

Forge at about 1625° (salmon).

Harden in water at 1400° to 1450° (medium cherry red).

Anneal at 1425° (medium cherry red).

SUITABLE FOR:

Hand Tools
Pneumatic Tools
Chisels, Hand Pneumatic

Beading Tools
Caulking Tools

CARRIED IN STOCK:

Octagons (not annealed). Sizes from $\frac{1}{4}$ up to $1\frac{1}{2}$ inches.

For complete list of all sizes carried in stock, see current issue of the Ryerson Journal and Stock List or refer to Stock Supplement in back of this book.

Ryolite High Speed Steel

Identification Color—Blue

In offering this grade of steel to our customers we feel safe in saying there is no better grade of high speed steel on the market, inasmuch as our product is made from the best procurable raw materials and by the most approved method of manufacture.

High speed steel is used for heavy duty work, in lathe tools, planer tools, shaper tools, certain classes of dies and

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for special purposes. High speed steel should be hardened carefully because its performance depends as much on the correct method of hardening and tempering as it does on the steel itself.

HEAT TREATMENT:

In forging high speed steel use a lemon to light yellow color and work the steel rapidly with light blows, returning the piece to the fire as often as necessary, so as to maintain a good high forging temperature at all times. High speed steel is ruined by low temperature forging.

On account of the high cost of the steel, we suggest that the work be sent out to be hardened, unless your shop has the necessary equipment and experience to do the job properly.

In hardening high speed steel the temperature is raised slowly to a salmon color. The heat should then be increased as rapidly as possible to almost a welding temperature. At this point the steel will look "wet" on the surface and the temperature should be about 2300 degrees Fahrenheit.

Quench high speed steel in oil or in strong dry air blast until it is down to about 400 degrees Fahrenheit and draw the temper at once.

Great care must be used not to burn the thin cutting edges, as this is quite likely to happen at the high temperature needed to harden the steel.

An open fire may be used, provided it is deep and clean, and the blacksmith has had plenty of experience with high speed steel. The blast is cut down for the initial heating and turned on for the final quick heat.

Where furnaces are used, it is best to use two for this work. The one is held at the preheating temperature and the other at the high quenching heat. As soon as the tools have reached the heat of the low temperature furnace they are transferred to the high temperature furnace and heated rapidly.

All hardened high speed steel should be drawn to a temperature of 1100 to 1150 degrees Fahrenheit. This will make the steel harder and tougher and materially improve its cutting qualities.

CARRIED IN STOCK:

Can be furnished in practically all standard sizes.

Ryolite High Speed Tool Holder Bits

Ryolite tool holder bits are made from our standard grade high speed steel and are hardened under the most advantageous conditions by men who have had years of experience in this work. They are designed for use in all standard tool holders.

We offer these high speed bits under an assurance of uniformity and high quality. Each bit is stamped with the name "Ryolite" and we are quite sure that you will find them to be equal to any and superior to the majority of the other brands on the market. These bits are packed in substantial boxes with slide tops.

CARRIED IN STOCK:

Squares— $\frac{3}{16}$, $\frac{1}{4}$, $\frac{5}{16}$, $\frac{3}{8}$, $\frac{7}{16}$, $\frac{1}{2}$, $\frac{5}{8}$, $\frac{3}{4}$, $\frac{7}{8}$ and 1 inch.
Flats— $\frac{1}{4} \times \frac{3}{8}$, $\frac{5}{16} \times \frac{7}{16}$, $\frac{7}{16} \times \frac{9}{16}$, $\frac{3}{8} \times \frac{1}{2}$, $\frac{1}{2} \times \frac{5}{8}$, $\frac{1}{2} \times \frac{3}{4}$, $\frac{5}{8} \times \frac{7}{8}$.

Ryolite Special High Speed Tool Holder Bits

These bits are made of an entirely new analysis steel and are intended for the heaviest and fastest kind of cutting. They will work satisfactorily on hard and difficult jobs where the standard High Speed Bits will fail utterly. Ryolite Special High Speed Bits do not have their best cutting qualities on the surface and therefore about $\frac{1}{32}$ " must be ground off of all cutting surfaces if good results are to be obtained. Try these bits on your hardest job and you will be surprised at the result.

CARRIED IN STOCK:

Squares— $\frac{5}{16}$, $\frac{3}{8}$, $\frac{7}{16}$, $\frac{1}{2}$, $\frac{5}{8}$, $\frac{3}{4}$, and 1 inch.

ALLOY STEEL SECTION



Introduction

Alloy steel like tool steel especially when purchased in the untreated form represents an uncertain variable. Many manufacturers are able to bring out and develop the latent qualities to the full and secure remarkable results. Others secure only a portion of the possibilities of the product.

Therefore we have endeavored in a rather limited space to give as much definite information as we possibly can, and our suggestion is that the various tables and data supplied be taken more as a general guide to the subject than accurate, specific information. The reason for this suggestion is that the use of alloy steels, their physical properties, and chemical characteristics vary greatly, depending on the actual application. In a brief space, it is not possible to go into the subject in such detail that all various conditions can be fully covered.

Where the information we have given obviously covers your application, then further comment is unnecessary but where the problem does not seem to be fully answered, we would be very glad to have the matter taken up with us specifically, at which time we can probably furnish additional information which will enable you to secure the best possible results.

Quality

(Analysis not the only factor)

IT seems appropriate at the start to call the attention of the reader to the matter of quality of the alloy steel which he may contemplate buying and using.

Practically all users of alloy steels have been in the past, or are at present, users of tool steels, and they will therefore understand that chemical analysis is far from being the only factor governing the ultimate result to be obtained from the use of any steel.

All tool and die makers know the difference between a piece of common grade tool steel and a piece of special grade tool steel, even if the carbon content of each is exactly the same and general analysis very close in both grades. The real difference in the two steels mentioned is in the method of manufacture. This is governed by such factors as the kind of raw material used, the method of melting and casting, the amount of steel cut off the end of the original ingot, the amount of rolling or hammering done and the care used in annealing and inspecting the finished bars.

A mild steel bar is in the majority of cases used just as it is received from the mill. If, therefore, it satisfactorily passes mill inspection for size and freedom from surface defects it will generally be satisfactory to the ultimate consumer. Tool steel, on the other hand, as received from the mill has only started its journey, and it may be said that its manufacture is not completed until it has passed through its final process, which consists of heat treatment or hardening.

Inasmuch as practically all of the alloy steel purchased is subject to heat treatment before use,

it would therefore seem that alloy steels, like tool steels, cannot be judged entirely by their analysis. It is well known to alloy steel manufacturers that the ability of these steels to withstand the severe stresses put upon them by heat treatment depends not only on their analysis or composition, but also on the various processes through which they have passed during the period of manufacture at the mill.

For these reasons it should be clearly remembered that in purchasing alloy steels the reliability and reputation of the manufacturer should be given full consideration. The element of original cost must not be overlooked in order to secure economical production; but it is equally important to remember that each finished part represents just so much money spent for machine work and heat treating, and in most cases a cent or a fraction of a cent per pound in the initial cost is a very small factor when compared with the money expended on machine work, heat treating, freight, and other elements of the total cost.

Method of Manufacture

Alloy steels are being manufactured by the following processes:

Crucible Process.

Open Hearth Process.

Electric Furnace Process.

The crucible process, owing to extreme cost, is not used for heavy tonnage production, and need not be considered by the average manufacturer, it being impossible to produce a strictly crucible melted alloy steel at a price sufficiently low to enable the user to compete with others who are using steel made by one of the other methods.

A discussion of the relative merits of the open hearth process and electric furnace process would

cover far more space than is permitted in this book and would also of necessity be extremely technical.

Steel of the very best quality can be made by either the electric furnace or the open hearth process, and it is perhaps safe to assume that the ultimate quality depends more on the selection of raw material, care used in manufacturing, and knowledge and experience of the maker rather than the particular method which he follows in making the steel.

After all, the best solution of this problem for the average shop is to buy material from an entirely reliable source of supply, specifying the purpose for which the material is to be used and leaving it to the sellers to furnish steel in which they have confidence and on which they are willing to stake their reputation.

How to Buy and Select Alloy Steels

Perhaps one of the most difficult problems that must be solved by the user of alloy steels is the selection of a suitable grade to use for a certain piece of work.

A study of the table on page 65 (Table A) will show that somewhat similar physical characteristics may be obtained from the use of any one of the several commercial grades of alloy steel mentioned, and the user will, therefore, perhaps, be at a loss to decide which class of steel to select. For this reason we call attention to the following.

There are many elements which must be taken into consideration besides the actual physical properties which may be obtained from any one grade of steel. Among these may be mentioned availability, cost, machining qualities, equipment necessary for heat treatment, and past experience of the user in handling the steel selected.

The largest warehouse tonnages of alloy steel are confined to the chrome nickel steels, containing

about 1 to 1.5 per cent nickel and .40 to .75 per cent chromium; the 3½ per cent nickel steels (carbon contents varying in both); and high manganese steels containing between 1% and 2% manganese.

These three types of alloy steel are suitable when properly heat treated for the manufacture of such parts as axles, jack shafts, oil hardened and case hardened gears, high duty bolts and nuts, cams, crank shafts, connecting rods, and the thousand and one different parts entering into the manufacture of automobiles, trucks, tractors, and other special machines.

TABLE A

COMPARATIVE PROPERTIES OF ALLOY STEELS

The following are the approximate physical properties which may be obtained from some of the alloy steels under ideal conditions of heat treatment.

GRADE OF STEEL	TENSILE STRENGTH Lbs. per sq. inch	YIELD POINT Lbs. per sq. inch	REDUCTION OF AREA Per Cent of Original area	ELONG- ATION Per Cent in 2 inches	BRINELL HARD- NESS
CHROME NICKEL S. A. E. 3135					
Natural Condition	75,000	50,000	50	15	230
Heat Treated	220,000	200,000	40	9	390
3½ PERCENT NICKEL S. A. E. 2320					
Natural Condition	70,000	50,000	60	18	220
Heat Treated	170,000	140,000	50	14	360
3½ PERCENT NICKEL S. A. E. 2340					
Natural Condition	85,000	60,000	45	14	240
Heat Treated	240,000	220,000	37	10	450
HIGH MANGANESE (30-40 Carbon)					
Heat Treated	110,000	85,000	60	23	200

The analysis ranges most commonly used in chrome nickel and 3½ per cent nickel steels are as follows:



Steam Hammer. Used for general forging, such as bars, rings, discs, shafts, etc.

Photograph Courtesy The Atlas Forging Co., Chicago



Molten metal being poured from ladle into the ingot molds.

A L L O Y S T E E L I N S T O C K

LOW CARBON CHROME NICKEL STEEL

(S. A. E. Specification 3115)

Carbon.....	0.10 to 0.20
Nickel.....	1.00 to 1.50
Chromium.....	0.45 to 0.75
Manganese.....	0.30 to 0.60
Phosphorous maximum.....	0.04
Sulphur maximum.....	0.045

LOW CARBON CHROME NICKEL STEEL

(S. A. E. Specification 3120)

Carbon.....	0.15 to 0.25
Nickel.....	1.00 to 1.50
Chromium.....	0.45 to 0.75
Manganese.....	0.30 to 0.60
Phosphorus maximum.....	0.04
Sulphur maximum.....	0.045

HIGH CARBON CHROME NICKEL STEEL

(S. A. E. Specification 3135)

Carbon.....	0.30 to 0.40
Nickel.....	1.00 to 1.50
Chromium.....	0.45 to 0.75
Manganese.....	0.50 to 0.80
Phosphorus maximum.....	0.04
Sulphur maximum.....	0.045

HIGH CARBON CHROME NICKEL STEEL

(S. A. E. Specification 3140)

Carbon.....	0.35 to 0.45
Nickel.....	1.00 to 1.50
Chromium.....	0.45 to 0.75
Manganese.....	0.50 to 0.80
Phosphorus maximum.....	0.04
Sulphur maximum.....	0.045

LOW CARBON 3½ PER CENT NICKEL STEEL

(S. A. E. Specification 2315)

Carbon.....	0.10 to 0.20
Manganese.....	0.30 to 0.60
Phosphorus maximum.....	0.04
Sulphur maximum.....	0.045
Nickel.....	3.25 to 3.75

JOSEPH T. RYERSON & SON, INC.

LOW CARBON 3½ PER CENT NICKEL STEEL
(S. A. E. Specification 2320)

Carbon.....	0.15 to 0.25
Manganese.....	0.50 to 0.80
Phosphorus maximum.....	0.04
Sulphur maximum.....	0.045
Nickel.....	3.25 to 3.75

HIGH CARBON 3½ PER CENT NICKEL STEEL
(S. A. E. Specification 2330)

Carbon.....	0.25 to 0.35
Manganese.....	0.50 to 0.80
Phosphorus maximum.....	0.04
Sulphur maximum.....	0.045
Nickel.....	3.25 to 3.75

HIGH CARBON 3½ PER CENT NICKEL STEEL
(S. A. E. Specification 2335)

Carbon.....	0.30 to 0.40
Manganese.....	0.50 to 0.80
Phosphorus maximum.....	0.04
Sulphur maximum.....	0.045
Nickel.....	3.25 to 3.75

HIGH CARBON 3½ PER CENT NICKEL STEEL
(S. A. E. Specification 2340)

Carbon.....	0.35 to 0.45
Manganese.....	0.50 to 0.80
Phosphorus maximum.....	0.04
Sulphur maximum.....	0.045
Nickel.....	3.25 to 3.75

HIGH CARBON 3½ PER CENT NICKEL STEEL
(S. A. E. Specification 2345)

Carbon.....	0.40 to 0.50
Manganese.....	0.50 to 0.80
Phosphorus maximum.....	0.04
Sulphur maximum.....	0.045
Nickel.....	3.25 to 3.75

A L L O Y S T E E L I N S T O C K

HIGH CARBON 3½ PER CENT NICKEL STEEL

(S. A. E. Specification 2350)

Carbon.....	0.45 to 0.55
Manganese.....	0.50 to 0.80
Phosphorus maximum.....	0.04
Sulphur maximum.....	0.045
Nickel.....	3.25 to 3.75

LOW CARBON HIGH MANGANESE SCREW STOCK

Carbon.....	0.10 to 0.20
Phosphorus maximum.....	0.05
Sulphur.....	0.08 to 0.13
Manganese.....	1.00 to 1.20

These steels are available from stock in practically all sizes from ⅜ to 6 inches in hot rolled rounds. The S. A. E. 2315, 2320, 3115 and 3120 steels are also carried in cold drawn bars.

It is not always possible to obtain the size or quantity of steel needed in the particular analysis desired, and we therefore show a possible substitution list. A study of this list will show that where a certain analysis is specified one or more of the other alloy steels can probably be used in its place with satisfactory results. It must not, of course, be taken for granted that this will hold true in each and every case, and where a doubt exists the matter should be referred to some authority on the subject. In using the substitution list it is of the utmost importance that the heat treatment of the substitute steel be carefully considered, inasmuch as in all probability it *will not be the same* as the treatment of the originally specified analysis.

APPROXIMATE SUBSTITUTION LIST

Steel Specified S. A. E. No.	Possible Substitution S. A. E. No.		
3115	2315 2320	3120 High Manganese Screw Stock	6120
3120	2315 2320	3115 High Manganese Screw Stock	6120
3130	2320 2330 2335	3120 3135 3140	6120 6125 6130
3135	2330 2335 2340	3130 3140	6125 6130 6135
3140	2330 2335 2340 2350	3135	6130 6135
2315	2320	3115 3120 High Manganese Screw Stock	6120
2320	2315	3115 3120 High Manganese Screw Stock	6120
2330	2320 2335 2340	3130 3140	6125 6130 6135
2335	2330 2340	3135 3140	6125 6130 6135
2340	2330 2335 2350	3135 3140	6130 6135
2350	2340	3140	6135
6120	2315 2320	3115 3120 High Manganese Screw Stock	..... ..... .....

APPROXIMATE SUBSTITUTION LIST—*Continued*

Steel Specified S. A. E. No.	Possible Substitution S. A. E. No.		
6125	2330	3130	6120
	2335	3140	6130
6130	2330	3130	6125
	2335	3135	6135
	2340	3140	
6135	2335	3135	6130
	2340	3140	
	2350		
High Manganese Screw Stock	2315	3115	6120
	2320	3120	

It must be clearly remembered that in selecting an alloy steel for any special purpose the physical properties of the steel in its heat treated condition must determine its use. Alloy steels in the untreated or natural condition undoubtedly have advantages over the non-alloy steels, but the advantages are not sufficient to warrant the increased cost. Another factor in this matter is that no reliance can be placed on the physical properties of untreated alloy steels. These physical properties will vary widely in bars of different sizes and also in different bars of the same size. This condition depends upon the amount of work which has been done on the steel at the mill and also largely on the final temperature of rolling.

The most readily procured alloy steels may be roughly divided into two classes, the first being of low carbon content and the second of relatively high carbon content. These two classes are naturally used for widely divergent purposes. In order to assist the prospective user we will endeavor to give a brief outline of the general application of the two classes of material.

Low Carbon Alloy Steels

The low carbon alloy steels, such as high manganese, screw stock, chrome nickel (S. A. E. 3115 and

3120) and $3\frac{1}{2}$ per cent nickel (S. A. E. 2315 and 2320) with a carbon range of from 0.10-25 per cent, are used primarily for parts which are to be case hardened. They are also used for certain structural purposes such as spring clips, bolts, and other parts which will be subjected to frequently alternating stresses and intense vibration. When properly heat treated these low carbon steels, though not developing a very high tensile and elastic limit, show a very fine fibrous structure and one having consequently great resistance to fatigue, or what is commonly but erroneously known as crystallization.

Owing to the ability of these low carbon steels to stand relatively high temperatures without deterioration, they are particularly suitable for drop forging.

High Carbon Alloy Steels

The most popular and generally used high carbon alloy steels have a carbon range of from .30 to .55 per cent carbon, and can readily be obtained in either chrome nickel (S. A. E. 3135 and 3140) or $3\frac{1}{2}$ per cent nickel (S. A. E. 2330, 2335, 2340, 2345 and 2350) grades.

These higher carbon steels are used in the most part for structural purposes where relatively high yield points coupled with a reasonable degree of toughness are required.

The physical properties obtainable by heat treatment of high carbon alloys render them suitable for the manufacture of such parts as crank shafts, connecting rods, counter shafts, rocker arms, gears, keys, and in fact all parts where high physical properties are necessary.

It has been found very advantageous to use some of these alloy steels in the manufacture of certain parts of machine tools such as lathe spindles, milling machine spindles, and other parts where the least

amount of bending under severe stress would render the tool entirely useless. By the use of these high grade steels the weight of many machines can be materially lowered without in any way impairing their efficiency or reducing their load capacity.

The higher carbon alloys can be successfully drop forged, although they cannot with safety be worked at as high temperatures as the lower carbon series.

From the preceding remarks in this chapter the reader will have noted that the selection of the correct grade of alloy steels presents several more or less technical problems, and these problems are supplementary to the very important question of availability. In view of these conditions we believe that the most satisfactory method of handling this problem will be to take the matter up in detail with some reliable source of supply. The sellers of special alloy steels naturally have available the services of men thoroughly familiar with the various problems of alloy steel procurement and use, and, therefore, although they do not know all that is to be known, they are in a position frequently to give advice which will save both time and money for the user.

Heat Treatment of Alloy Steel

The heat treatment of alloy steel in its essential characteristics does not differ from the general practice used in heat treating tool steel. For that matter from a strictly accurate standpoint, tool steel is just as much an alloy steel as chrome nickel, 3½ nickel, or any of the other grades ordinarily classed under the heading of alloy steel.

The same general care in heating, quenching, forging, etc., must be applied to alloy steel, as it is to tool steel. However, owing to the fact that alloy steels are seldom hardened to the extent which is common practice with tool steel, the same accuracy of temperature control is, as a rule, not necessary

It is important to bear in mind that alloy steel in the untreated condition, while better as a rule than straight carbon steel, is not capable of giving the fine service and high physical properties which are developed after proper heat treatment. It is a pity to pay a higher price for a good quality alloy steel and then use it in the natural condition, as it is then capable of developing only a half, or even less of the physical properties which can be brought out by a simple and inexpensive heat treatment. Our recommendation is that wherever possible, alloy steels be heat treated. If this is done properly, the user knows definitely what physical properties have been developed and knows to what extent he can depend upon the steel to withstand the stresses which are put upon it.

The tables shown on heat treatment and physical properties are a general guide as to what may be expected in the way of tensile strength, yield point, hardness, etc., when the different grades of alloy steel are subjected to the various processes of heat treatment.

These figures are, of course, merely an indication and must not be taken too literally, as local conditions and accuracy of heat treatment will have a material effect on the final result.

All tests for tables of this character are made with relatively small bars, usually in the neighborhood of $1\frac{1}{4}$ " round. When larger bars are involved, the physical properties will be considerably lower. We have made an attempt to give at the bottom of these tables a percentage discount covering the physical properties of larger diameter bars, and we believe that if this is used carefully, a fairly accurate result can be predicted.

Case Hardening or Carbonizing

It is sometimes desirable to produce a piece of steel having an intensely hard exterior or surface, intended to resist wear, coupled with a tough and strong core or center having considerable resistance to shock.

This result is obtained by what is commonly known as case hardening or carbonizing. This process consists of taking a low carbon steel, and, after having formed it to the desired shape, raising the carbon content on the surface to a sufficiently high point so that when quenched the surface will become extremely hard. While under certain conditions steel can be made to absorb carbon, such absorption or penetration will not extend very far beneath the surface; and, therefore, when this material is quenched the interior, being of low carbon content, will merely be toughened, thus giving an extremely hard surface with a tough and strong supporting core or center.

Various materials under certain heat conditions will give up some of their carbon to steel. Among those commonly used are charred leather, crushed and charred bone, charcoal, and certain gases which contain a large percentage of carbon in one form or another.

In commercial case hardening the pieces to be treated are packed in a box or container and are surrounded with the carbonizing material, which may consist of one of the foregoing substances or, better, one of the numerous prepared carbonizing mixtures, that are sold for this purpose. The box is now raised to a certain temperature in the furnace and held at this temperature for a definite length of time. When sufficient carbon penetration has taken place the parts are subjected to various heat treatments which will be described later.

The rate of case hardening and the depth of pene-

tration are controlled by the following factors:

First, the class of steel.

Second, the class of carbonizing mixture.

Third, the shape of and the material from which the box or container is made.

Fourth, the temperature at which the carbonizing is done and the length of time during which this temperature is maintained.

Roughly speaking, the higher the temperature, the more rapidly will the carbonizing mixture give up its carbon to the steel, but this heat factor is governed by the degree of heat which the steel can stand without detrimental effect; and, therefore, a deep penetration can only be obtained safely by using the normal case hardening temperature and holding this for a length of time dependent on the depth of case required.

Attention is called to the following points in connection with this work.

Selection of Steel for Case Hardening

The hardness and depth of case and the strength and toughness of the core must all be considered in selecting a steel for case hardening.

It must be remembered that the relatively high temperatures used for this work are hard on any steel and therefore a steel must be selected which is able to withstand the long time heating without being seriously damaged.

As a rule, the lower the carbon the better will a steel stand up under high temperatures. However, the lower the carbon the less will be the strength of the core when heated and quenched.

In considering the core it will be recognized that a relatively low carbon steel must be used for two reasons; first, because it will not be so subject to grain growth during the carbonizing period and sec-

ond, because it must stay relatively soft and tough after the parts have been quenched.

A low carbon steel is particularly necessary for thin sections as these will cool fast when quenched and the core therefore is more likely to harden to the point of brittleness.

Large sections can be made of a higher carbon steel as the parts will cool more slowly when quenched and therefore the core will not tend to harden as much.

In no case should a steel of over 0.25 carbon be used as steel of higher carbon will deteriorate during the carbonizing process, and the core will be hard and brittle.

Carbonizing Mixtures

There are many good carbonizing mixtures available, all having their good points. However, the following features should be considered when buying:

First, should have a good heat conductivity.

Second, should be uniform in granular size.

Third, must carbonize at a uniform rate.

Fourth, must be capable of being used time after time in order to be economical.

Fifth, should not contain phosphorus or sulphur, inasmuch as these may be absorbed by the steel.

Sixth, must be of uniform composition throughout so that it will give uniform results on all parts of the steel being carbonized.

Case Hardening Boxes

The boxes used for hardening should be sufficiently heavy to withstand the high temperature used for a considerable length of time without warping, and should be made of material which is a good heat conductor. It is important that the boxes be so designed that after the pieces are packed in them they

can be closed so as to exclude all air. Iron pipe is satisfactory for small pieces, although cast boxes are more generally used. Where long runs are contemplated it is economical to use boxes made from certain alloys. These special boxes are advertised in the trade journals and can be readily procured.

Carbonizing Furnaces

Furnaces for carbonizing should be such that the temperature can be accurately controlled over any desired period of time, and in this respect they, of course, do not differ from furnaces used for other heat treating operations.

Temperature for Case Hardening

There are so many factors, such as the character of the steel, kind of case hardening mixture used, the size of the case hardening boxes, depth of penetration desired, etc., that govern case hardening temperature that it is almost impossible to give any accurate data on this subject. The following list will probably be useful as a general guide on this subject, although it must be modified to meet special conditions.

CARBON STEEL S. A. E. 1020

.10 to .25 carbon, 1650° to 1700° Fahr.

COLD FINISHED HIGH MANGANESE SCREW STOCK

.10 to .20 carbon, 1625° to 1675° Fahr.

3½ PER CENT NICKEL STEEL S. A. E.

2315 AND 2320

1625° to 1675° Fahr.

CHROME NICKEL STEEL S. A. E. 3115 AND 3120

1625° to 1700° Fahr.

Depth of Penetration

The depth of penetration depends on numerous factors which have already been mentioned, and,

owing to there being so many things that have a bearing on this matter, it is hardly practical to make any definite statement in regard to depth of penetration which may be expected for a given time and temperature.

In case hardening it must be remembered that the temperature of the furnace is not the same as the temperature of the piece being case hardened. The heat has to first penetrate through the walls of the box and then through the case hardening mixture, and consequently the piece being carbonized will be at a lower temperature than the furnace itself.

Where accurate results are required it is a good plan to make a few experiments by placing a thermo couple in the box near the pieces being treated, and also another thermo couple in the furnace so the difference in temperature between the furnace and the piece can be observed.

Heat Treatment After Carbonizing

When carbonization has been completed the hardening process is next undertaken, and it is of the greatest importance that this be carried out accurately and scientifically if uniform and dependable results are to be obtained.

It must be remembered that the carbonized pieces have been held at a temperature considerably above the critical range during a long period of time; and it, therefore, follows that the grain of the steel has been coarsened.

After hardening, the surface or case of a carbonized part will be intensely hard and brittle, and will in consequence not have any great degree of toughness. For these reasons it is necessary that we depend on the center or core of the piece to support the hard outside surface; and we must, therefore,

bend our efforts toward putting the core in the best possible condition in regard to granular structure, strength, and elasticity.

Speaking generally, the best method of obtaining this result is by first cooling the parts slowly, this being accomplished by allowing them to remain in the case hardening boxes until comparatively cold, then removing and proceeding with a refining treatment.

On page 81 will be found formulæ which may be used as a general guide for carbonizing operations. The important fact to remember is that no set rule can be given to cover all cases. Where a new job is undertaken time and money will be saved if the heat treater will take samples of the steel he intends working with, and then submit them to the process he contemplates using for the work in hand. Should the treatment contemplated not be correct, the samples will show it and steps can be taken to avoid the loss of material and time that would result had tests not been made. It must be realized that experience and patience are necessary when good dependable results are to be obtained. Your first batch may turn out well. If it does you are very fortunate, but if it does not, don't be discouraged. If you fail there is a reason. Study it out and correct it next time.

Packing

Inasmuch as the heat in case hardening must penetrate first through the containing boxes and then through the case hardening mixture before reaching the surface of the steel, it is obvious that a uniform temperature on all parts of the piece being case hardened can not be obtained unless the piece is surrounded on all sides by equal thickness of case hardening mixture. As the rate and depth of penetration depend upon the temperature, it is

obvious that to obtain uniform results we must surround the pieces being case hardened as nearly as possible with a uniform amount of case hardening mixture.

Packing is an important operation in case hardening and care should be used to see that the pieces being treated are placed as nearly as possible in the center of the case hardening box and that the carbonizing mixture is packed uniformly on all sides.

It is not wise to use very large case hardening boxes or to endeavor to place too many parts in the one box. When this is done the parts nearest the wall of the box will naturally attain a very much higher temperature than those near the center, and a nonuniform result will be secured.

Superficial Case Hardening. Where an extremely thin surface of hardened steel is required, and in cases where such hardening must be obtained quickly, the following method may be employed, although the results are not uniform nor, as a rule, particularly good:

Melt sufficient potassium cyanide in a pot so as to form a bath in which the parts to be case hardened may be immersed.

Raise the temperature of the molten potassium cyanide to about 1550° Fahr., and allow the parts to remain in this bath for about fifteen minutes. The length of time that the parts remain in the cyanide bath will depend on their size, but in any event it will be necessary that they remain for a sufficient length of time to insure uniform heat penetration all the way through to the center.

Ten minutes immersion will give a penetration of about 0.005 inch and twenty minutes a penetration of about 0.01 inch when using a straight carbon steel such as S. A. E. 1020.

The pieces should be removed from the cyanide bath and plunged directly into cold water, after which the surface will be found to be hard and the interior core in a fairly good condition.

Great care must be used in employing a molten cyanide bath, inasmuch as this material will give off highly poisonous fumes which should be carried off by suitable apparatus.

In case hardening it must be borne in mind that there are two objectives: The first, which is well known and commonly recognized, consists in obtaining a hard exterior surface, intended, of course, to resist wear and abrasion. The other, which is frequently overlooked although of equal importance, is the building up of a core of adequate strength and toughness so that it may give the proper support to the exterior or wearing surface.

In case hardening we believe it very necessary to examine the finished pieces in a more comprehensive manner than merely testing the exterior for hardness. The core examination referred to can be carried out by either cutting through one of the pieces, polishing the section and subjecting it to microscopic examination, or, in the event of the lack of the necessary equipment for such examination, a very good idea can be obtained by partially cutting through the piece and then fracturing. This will give an opportunity to examine the granular structure of the steel, and the thickness of the case.

Typical Formulæ for Carbonizing

CHROME NICKEL STEEL S. A. E. 3120:

Carbonize at 1625° to 1700°	Re-heat to 1300° to 1400°
Cool in box and remove.	Quench in oil or water.
Re-heat to 1550° to 1600°	Draw to from 300° to 450°
Quench in oil.	

3½% NICKEL STEEL S. A. E. 2320:

Carbonize at 1625° to 1675°	Re-heat to 1300° to 1400°
Cool in boxes and remove.	Quench in oil or water.
Re-heat to 1550° to 1575°	Draw to from 300° to 450°
Quench in oil.	

CARBON STEEL S. A. E. 1020:

Carbonize at 1650° to 1700°	Re-heat to 1400° to 1450°
Cool in boxes and remove.	Quench in oil or water.
Re-heat to 1550° to 1600°	Draw to about 400°
Quench in oil.	

HIGH MANGANESE SCREW STOCK:

Carbonize at 1625° to 1675°	Re-heat to 1475° to 1525°
Cool in box.	Quench in oil or water.
Re-heat to 1600° to 1650°	Draw to from 300° to 450°
Quench in oil.	

The above formulæ are approximate and will be subject to change according to the size of pieces being carbonized and also the depth of penetration required. The final drawing temperature will have to be modified, depending on the degree of hardness required in the finished article.

As in all other heat treating operations, definite formulæ for carbonizing can best be obtained by actual experiment and a little time and money spent in this way will be well invested inasmuch as it will save the possible damaging of valuable work.

Annealing Temperatures

STRAIGHT CARBON STEELS

.15 to .25 Carbon	1570° Fahr.
.25 to .35 Carbon	1550° Fahr.
.35 to .45 Carbon	1525° Fahr.
.45 to .55 Carbon	1500° Fahr.
.85 to 1.10 Carbon (Tool Steel)	1425° Fahr.

3½ PER CENT NICKEL STEEL

.10 to .20 Carbon	1575° Fahr.
.15 to .25 Carbon	1575° Fahr.
.25 to .35 Carbon	1500° Fahr.
.35 to .45 Carbon	1475° Fahr.

CHROME NICKEL STEEL

(S. A. E. Specification 3120 to 3140)

.10 to .20 Carbon	1575° Fahr.
.15 to .25 Carbon	1575° Fahr.
.25 to .35 Carbon	1500° Fahr.
.35 to .45 Carbon	1475° Fahr.

Approximate Comparison of Hardness and Tensile Strength

It has been found that Brinell hardness bears a fairly uniform relation to tensile strength. When lack of equipment or time makes it impossible to run accurate tests on tensile strength, a Brinell test will give a fairly dependable idea of the strength of the material.

The following list may be used as a guide for such tests, the figures, of course, being considered as only approximate.

A L L O Y S T E E L I N S T O C K

CARBON STEEL

Scleroscope Reading	Brinell Reading	Tensile Strength in lbs. per sq. inch
20	130	63,000
30	195	108,000
40	260	150,000
50	325	200,000
60	390	250,000
70	455	290,000
80	520	335,000
90	585	390,000
100	650	425,000

CHROME NICKEL STEELS

Scleroscope Reading	Brinell Reading	Tensile Strength in lbs. per sq. inch
20	141	74,000
30	195	111,000
40	249	147,000
50	303	183,000
60	357	215,000
70	411	258,000
80	465	292,000
90	519	331,000
100	573	366,000

3½ PER CENT NICKEL STEELS

Scleroscope Reading	Brinell Reading	Tensile Strength in lbs. per sq. inch
20	158	70,000
30	213	100,000
40	268	145,000
50	323	180,000
60	378	225,000
70	433	260,000
80	488	280,000
90	543	320,000
100	598	350,000

3½% NICKEL STEEL 15-25 CARBON

S. A. E. SPECIFICATION 2320

Quenching Temperature 1500-1525° F. in Oil.

Annealing Temperature 1425-1450° F.

Approximate physical properties of 1¼" Rd. bar
quenched at above temperature and drawn.

Drawing Temperature	Tensile Strength	Yield Point	Elong. in 2 Inch	Red. of Area	Brinell Hardness	Sclero-scope Hardness
500	165,000	135,000	12.0%	48.0%	321	49
600	155,000	124,000	14.5%	52.0%	302	47
700	144,000	112,000	16.9%	56.3%	295	45
800	132,000	99,000	19.2%	60.0%	272	42
900	120,000	86,000	22.4%	63.2%	251	38
1,000	107,000	74,000	24.5%	66.1%	239	37
1,100	94,000	64,000	26.7%	69.0%	207	31
1,200	82,000	55,000	29.0%	72.0%	169	24

3½% NICKEL STEEL 35-45 CARBON

S. A. E. SPECIFICATION 2340

Quenching Temperature 1425-1450° F. in Oil

Annealing Temperature 1425-1475° F.

Approximate physical properties of 1¼" Rd. bar
quenched at above temperature and drawn.

Drawing Temperature	Tensile Strength	Yield Point	Elong. in 2 Inch	Red. of Area	Brinell Hardness	Sclero-scope Hardness
500	243,000	208,000	12.0%	37.0%	482	70
600	225,000	203,000	13.0%	43.0%	453	66
700	204,000	185,000	14.5%	47.0%	407	62
800	178,000	160,000	16.0%	53.0%	361	56
900	156,000	138,000	18.0%	57.0%	317	49
1,000	138,000	118,000	21.0%	60.0%	279	43
1,100	124,000	105,000	23.0%	62.0%	248	38
1,200	110,000	90,000	25.0%	63.0%	225	34

If larger bars are being heat treated reduce the tensile and yield point approximately in accordance with the following table:

Size	2½	3	3½	4	4½	5	5½	6
Reduce by %	10.0	13.5	16.5	17.8	18.5	19.2	19.6	20.0

ALLOY STEEL IN STOCK

CHROME NICKEL STEEL 15-25 CARBON S. A. E. SPECIFICATION 3120

Quenching Temperature 1575-1600° F. in Oil.

Annealing Temperature 1475-1500° F.

Approximate physical properties of 1¼" Rd. bar
quenched at above temperature and drawn.

Drawing Temperature	Tensile Strength	Yield Point	Elong. in 2 Inch	Red. of Area	Brinell Hardness	Sclero-scope Hardness
500	150,000	115,000	15.5%	54.0%	265	41
600	144,000	110,000	16.0%	57.0%	250	38
700	134,000	102,000	16.5%	61.0%	240	37
800	123,000	95,000	18.0%	65.0%	225	35
900	111,000	84,000	21.0%	69.0%	205	31
1,000	100,000	74,000	24.5%	71.0%	185	27
1,100	91,000	66,000	28.5%	71.5%	175	25
1,200	84,000	60,000	31.8%	72.0%	163	22

CHROME NICKEL STEEL 30-40 CARBON S. A. E. SPECIFICATION 3135

Quenching Temperature 1475-1525° F. in Oil.

Annealing Temperature 1400-1450° F.

Approximate physical properties of 1¼" Rd. bar
quenched at above temperature and drawn.

Drawing Temperature	Tensile Strength	Yield Point	Elong. in 2 Inch	Red. of Area	Brinell Hardness	Sclero-scope Hardness
500	230,000	208,000	8.0%	32.0%	407	62
600	220,000	198,000	10.0%	35.0%	392	60
700	202,000	177,000	11.5%	43.0%	370	57
800	180,000	150,000	13.0%	50.0%	340	52
900	155,000	127,000	15.0%	54.0%	310	48
1,000	138,000	110,000	17.0%	58.0%	287	44
1,100	120,000	98,000	19.0%	61.0%	255	39
1,200	106,000	87,000	21.0%	63.0%	228	35

If larger bars are being heat treated reduce the tensile and yield point approximately in accordance with the following table:

Size	2½	3	3½	4	4½	5	5½	6
Reduce by %	8.5	10.0	12.0	13.5	14.0	14.5	15.0	15.5

WORKING TEMPERATURES FOR CARBON STEELS

NAME	Carbon Content	Approx. Critical Temp.	Forging Temp.	Quenching Temp.
Machinery.....	0.25	1475	1650	1525-1575
Machinery.....	0.35	1395	1650	1450-1500
Machinery.....	0.45	1385	1650	1435-1485
Crucible Machy...	0.50	1380	1625	1430-1480
Crucible Machy...	0.55	1375	1625	1425-1475
Tool Steel.....	0.60	1365	1600	1400-1460
Tool Steel.....	0.70	1355	1600	1400-1460
Tool Steel.....	0.80	1350	1600	1375-1450
Tool Steel.....	0.90	1350	1575	1375-1450
Tool Steel.....	1.00	1350	1575	1375-1450
Tool Steel.....	1.10	1350	1500	1375-1430
Tool Steel.....	1.20	1350	1500	1375-1420
Tool Steel.....	1.30	1350	1500	1375-1420

HEAT TEMPERATURES AND COLORS
FOR HARDENING

CENTIGRADE DEGREES	FAHRENHEIT DEGREES	COLORS
538	1000	Black Red
649	1200	Blood Red
746	1375	Low Cherry Red
774	1425	Medium Cherry Red
815	1500	Full Cherry Red
843	1550	Bright Red
898	1650	Salmon
940	1725	Orange
996	1825	Lemon
1080	1975	Light Yellow
1205	2200	White

TEMPER COLORS OF STEEL PRODUCED BY HEAT
(FOR CARBON STEELS ONLY)

CENTIGRADE DEGREES	FAHRENHEIT DEGREES	COLORS
215	420	Faint Yellow
224	435	Light Yellow
232	450	Light Straw
238	460	Straw
252	485	Yellow Brown
260	500	Light Brown
268	515	Brown
274	525	Purple Brown
282	540	Purple
288	550	Dark Purple
299	570	Blue
315	600	Dark Blue

APPROXIMATE MELTING POINTS OF VARIOUS
MATERIALS

Element	Cent.	Fahr.	Element	Cent.	Fahr.
Aluminum.....	659	1218	Mercury.....	—39	—38
Antimony.....	630	1166	Molybdenum.....	2625°	4757
Barium.....	850	1562	Nickel.....	1452	2646
Bismuth.....	271	520	Nitrogen.....	—210	—346
Boron.....	2200?	3990?	Oxygen.....	—218	—360
Calcium.....	810	1490	Palladium.....	1549	2820
Carbon.....	3600	6510	Phosphorus.....	44	111
Chlorine.....	—102	—151	Platinum.....	1755	3191
Chromium.....	1520	2768	Potassium.....	62	144
Cobalt.....	1480	2696	Silicon.....	1420	2588
Copper.....	1083	1981	Silver.....	960	1761
Gold.....	1063	1945	Sodium.....	97	207
Hydrogen.....	—259	—434	Steel, Mild.....	1472	2680
Ice.....	Zero	32	Steel, Hard.....	1405	2560
Iodine.....	113	236	Sulphur S1.....	113	236
Iridium.....	2350	4262	Tantalum.....	2900°	5252°
Iron, Cast.....	1205	2200	Tin.....	232	450
Iron, Wrought.....	1593	2900	Titanium.....	1800	3272
Lead.....	327	621	Tungsten.....	3400°	6152°
Magnesium.....	651	1204	Vanadium.....	1720	3128
Manganese.....	1260	2300	Zinc.....	419	787

General Remarks

HAVING read the chapter on the theory of heat treating tool steel the reader will now understand the reasons underlying the following general remarks on the subject of the use of alloy steels.

If you are sure of what particular steel to use for a certain purpose, well and good; but if doubt exists in your mind, put the matter up to some reliable seller of this material. The sales department of the mills and the large warehouses are handling thousands of tons of alloy steel every day, and their wide experience will undoubtedly have covered the point about which you are uncertain.

Do not buy too much on a price basis. Original cost must naturally be taken into account; but in view of the large amount of work that is done on alloy steel in the way of machining and heat treating and the vital importance of the parts manufactured being up to standard, it is absolutely essential that first class material be obtained. Remember that analysis is not the only point to be considered in the selection of alloy steels. Freedom from pipes, seams and other defects, accuracy in the matter of size, straightness of the bars, finish of the surface, and many other points are of great importance. Steel may conform to your specification in analysis and yet be made in such a way that it will develop cracks, checks, or other defects when it is subjected to the violent action of a quenching process.

In heating alloy steels, do not place a cold bar in an extremely hot furnace. This will apply more in the case of larger bars, and the reason will be obvious if the notes on this subject as given in

another part of this book are read. Do not expect to get the same physical properties from a 10 inch round forging as you will from a 1 inch round bar just because the analysis may be the same and because you give it the same heat treatment. Where high physical properties are required from large forgings or large rolled bars, the desired result can to a certain extent be obtained by using a quenching temperature higher than that which would be used with a smaller section. However, irrespective of the size of the bar, the quenching temperature must not be raised to a point which will be detrimental to the steel. As a safe rule, do not exceed the quenching temperatures given in this book by more than 150° Fahr. Where large sections are being heat treated, higher physical properties will be obtained by raising the temperature, as already mentioned, and by using a quicker quenching medium; thus cold water may be substituted for oil in certain cases.

Do not place a heavy flat bar directly on the brick bottom of a furnace and then expect the lower part of the bar to have the same temperature as the top. Keep the pieces which you are heating slightly raised from the bottom of the furnace so that the hot gases can circulate around them, but in doing so place your supports sufficiently close together so that the hot bars will not sag down between the supports and thus become bent and crooked. A bar can be heated uniformly by placing it on the bottom of the furnace provided that it is turned over at frequent intervals. This method is satisfactory only in cases where a few pieces are being heated at once and where the operator can give the time necessary to constantly watch the heating operation. So arrange your shop that the distance between your furnace and the quenching bath is as short as possible. As soon as a steel has reached its proper quenching temperature all the way through to the

center, it should be immediately quenched, and it should be quenched on a rising or stationary heat and not on a falling heat. If the distance between the furnace and the quenching bath is great, or if the method of handling the steel is clumsy and inefficient, considerable time will elapse between removing the bars from the furnace and the actual quenching. When this condition exists it will be necessary to overheat the bars in the first instance, which will tend to give a poor result.

If time is lost between the removal of steel from the furnace and the quench, and should the bars be heated to the correct quenching temperature, then by the time they reach the bath they will have dropped below this point, and, in consequence, the heat treatment will not be effective.

When you have finished your work and submitted it to physical tests, you may find that your physical properties are either higher or lower than you intended them to be. The remedy will, of course, lie in a change of the heat treatment formula that you originally used; and it is, therefore, obvious that accurate records of all operations should be kept.

It is a good plan, where considerable work is being done, to use a regular heat treatment form. A place for the customer's name, order numbers, description of the parts, sizes, weights, etc., should appear at the top. Under this should appear your shop instructions or heat treatment formula, and opposite this space there should be blank spaces for the shop men to fill in the actual temperatures and times which were used in handling the job.

Such a record properly kept will give invaluable information in reference to any particular order that has been handled in the past, and can also be used as a basis for determining rapidly and accurately the most desirable heat treatment formula for other work.

Insist on the heat treating shop being kept clean and neat, and do not allow refuse bars and other scrap to accumulate. Such material gets in the way and cuts down the general shop efficiency, and there is always a possibility of bars of different analysis getting mixed up.

In selecting shop equipment for heat treating, do not depend on your own judgment too much unless you have had considerable past experience. Turn your problems over to reliable furnace people, and thus get the benefit of their experience for which they have probably paid a good price.

As we have explained elsewhere, rapid heating tends to expand the outside of a bar more quickly than the inside, thus giving it a tendency to crack. The reverse, of course, is true in quenching, inasmuch as the outside of the bar will shrink more rapidly than the inside, and this also has a tendency to crack the steel. For these reasons, it is obvious that square corners are to be avoided as much as possible, and wherever a radius or fillet can be used it renders the heat treatment much more safe.

Don't try to heat a piece of steel to 700° Fahr. in a furnace that shows a temperature of 1100 or 1200° Fahr. In other words, have your furnace at the maximum temperature which you desire the steel to attain, and then let the steel come up to the full furnace temperature. Where a furnace temperature is used which is in excess of the temperature desired in the steel, the outside part of the piece will reach the desired temperature before the inside, and you will not be able to allow the steel to remain in the furnace for sufficient length of time for the heat to penetrate all the way through.

Remember in drawing that the time element is of importance, and it is better to use a slightly lower temperature for a longer period of time, inasmuch as the changes brought about in the structure of the

steel by a certain drawing temperature are more uniform throughout the whole piece when this temperature can be held for a considerable length of time. Bear in mind that a certain drawing temperature held for an hour will produce the same physical properties as a much higher temperature held for ten minutes. The result of the long draw will, however, be more uniform and better.

When case hardening, select a good grade of case hardening mixture made by reliable people; by so doing your work will be more rapidly handled, carbon penetration will be more uniform, and the operation will be more economical inasmuch as you will be able to use the mixture over and over again with less frequent renewal than is necessary with a cheap compound.

When carbonizing any piece use a pot of suitable size. At no point should there be less than $1\frac{1}{4}$ inches of case hardening mixture between the inside of the pot and any surface of the piece being carbonized, and the more nearly $1\frac{1}{2}$ inches of case hardening mixture can be maintained all the way round the more uniform will be the result.

Always allow your carbonized parts to cool down slowly after the carbonizing process. If possible, allow the pots and their contents to cool down with the furnace and then follow the heat treating instructions which are given elsewhere.

Where pieces are to be case hardened, do not be satisfied with your work just because you have obtained a hard surface. A piece of common cold rolled shafting or screw stock or an ordinary mild steel bar can, by case hardening, be made just as hard on the surface as the highest grade of chrome nickel or other alloy steel. This is no indication, however, that a part has been produced which will do the work of a properly case hardened alloy steel

part. In some certain instances surface hardness is the only characteristic desired in case hardened work, but as a general thing the case hardened part must have strength as well as hardness, and this can only be obtained to the maximum degree by the use of a high grade alloy steel, properly treated.

This book has made no attempt to cover the technical features of alloy steel problems, and it has been necessary to write in a very general way, only covering a few of the more important points. The use of alloy steel will develop many difficult problems, a solution of which can only be given by experience. Should you, therefore, be uncertain in regard to selection of an alloy steel, its heat treatment, or its application, do not guess at the answer to your question, but put it up to the people from whom you are purchasing your steel.

Watch your furnace atmosphere. An excess of air is bound to give you trouble. The surface of your steel will decarbonize and will, therefore, not harden as it should, and heavy scale will be formed, sometimes ruining parts that are to be machined, or at any rate giving the machine shop a great deal of trouble with cutting tools that are called upon to remove this hard scale.

In forging alloy steels remember that steels containing chromium must not be forged at low heats, inasmuch as this will develop defects in the material. The low limit of heat for forging steel containing chromium will, of course, depend upon the percentage of carbon and chromium present, but it is fairly safe to assume that chrome nickel steels should not be forged at a temperature of less than 1550° Fahr.

Chrome nickel steel of a high carbon content (from .55 to .65 carbon), when properly heat treated makes a very fine die block and one which, while sufficiently soft to be machined, is hard enough and tough enough to last for a long period of time. This is a

great advantage in making certain drop forge dies, owing to the fact that the danger in quenching a machined die is eliminated. The manufacture of alloy steel die blocks is a specialty which can not be covered in this book, although those interested can obtain full information from the alloy steel producers.

When difficulty is experienced in getting furnace temperature so adjusted that scaling will not occur, the difficulty may be overcome by placing in the furnace some charcoal or a piece of wood. The wood or charcoal will combine readily with any free oxygen that may be present and thus prevent scaling or decarbonization of the steel.

Alloy Steels in Stock

S. A. E. 3115—Chrome Nickel Steel

S. A. E. 3115 is a case hardening steel for use when a deep case is required and along period of case hardening is necessary. Core ductility is a feature of this analysis. Its low carbon core will better resist long exposure to high temperatures without grain enlargement. It is also suitable for use in thin section parts. For heat treatment see page 81.

Hot rolled rounds are carried in stock in sizes from $\frac{1}{2}$ " to 6"; cold drawn rounds, $\frac{3}{4}$ " to $2\frac{1}{2}$ ". Forgings can also be furnished. For a complete list of sizes see the current issue of the Ryerson Journal and Stock List or refer to the supplement in the back of this book.

Carbon, 0.10 to 0.20; nickel, 1.00 to 1.50; chromium, 0.40 to 0.75; manganese, 0.50 to 0.80; phosphorous maximum, 0.04; sulphur maximum, 0.045.

S. A. E. 3120—Chrome Nickel Steel

S. A. E. 3120 is a case hardening steel which will develop the highest maximum core strength obtainable with the 3100 series of steels. The core is stronger and less ductile than that of 3115 and is therefore recommended for jobs of heavier section and where medium depth of case is satisfactory. For heat treatment see page 81.

Hot rolled rounds are carried in stock in sizes from $\frac{1}{2}$ " to 6"; cold drawn rounds, $\frac{3}{4}$ " to $2\frac{1}{2}$ ". Forgings can also be furnished. For a complete list of sizes see the current issue of the Ryerson Journal and Stock List or refer to the supplement in the back of this book.

Carbon, 0.15 to 0.25; nickel, 1.00 to 1.50; chromium, 0.40 to 0.75; manganese, 0.50 to 0.80; phosphorous maximum, 0.04; sulphur maximum, 0.045.

S. A. E. 3135—Chrome Nickel Steel

S. A. E. 3135 is a medium carbon steel suitable for axles, shafts and other heavy duty parts. Great strength, toughness and fair machinability are combined in this analysis. The heat treatment penetration is not as deep as with the higher carbon steels and therefore S. A. E. 3135 is used as a rule for the smaller sections. Oil quenching is generally employed. For heat treatment see page 81.

Rounds are carried in stock in sizes from $\frac{3}{8}$ " to 6". Forgings can also be furnished. For a complete list of stock sizes see the current issue of the Ryerson Journal and Stock List or refer to the supplement in the back of this book.

Carbon, 0.30; to 0.40; nickel, 1.00 to 1.50; chromium, 0.40 to 0.75; manganese, 0.50 to 0.80; phosphorous maximum, 0.04; sulphur maximum, 0.045.

S. A. E. 3140—Chrome Nickel Steel

S. A. E. 3140 is a higher carbon steel than S. A. E. 3135. The carbon is high enough for deep heat treatment penetration and is recommended for heavy section parts. Oil quenching is generally used in the heat treatment and very high physical properties are obtained. For heat treatment see page 81.

Rounds are carried in stock in sizes from $\frac{3}{8}$ " to 6". Forgings can also be furnished. For a complete list of sizes see the current issue of the Ryerson Journal and Stock List or refer to the supplement in the back of this book.

Carbon, 0.35 to 0.45; nickel, 1.00 to 1.50; chromium, 0.40 to 0.75; manganese, 0.50 to 0.80; phosphorous maximum, 0.04; sulphur maximum, 0.045.

S. A. E. 2315—3½ Per Cent Nickel Steel

S. A. E. 2315 is a case hardening steel for deep case work where core ductility is also required. It does not carbonize as quickly as the chrome nickel steels but it gives great core strength. It is recommended for long carbonizing application and thin section parts. For heat treatment see page 81.

Hot rolled rounds are carried in stock in sizes from $\frac{3}{8}$ " to 6"; and cold drawn bars in sizes $\frac{1}{2}$ " to $1\frac{1}{2}$ ". Forgings can also be furnished. For a complete list of sizes see the current issue of the Ryerson Journal and Stock List or refer to the supplement in the back of the book.

Carbon, 0.10 to 0.20; manganese, 0.50 to 0.80; phosphorous maximum, 0.04; sulphur maximum, 0.045; nickel, 3.25 to 3.75.

S. A. E. 2320—3½ Per Cent Nickel Steel

S. A. E. 2320 is a case hardening steel for use when a fairly hard core is desirable. It is suitable for heavy sections and applications where only a medium depth of case is needed. It is not as good as S. A. E. 2315 for use in thin section parts as the core may get too hard. For heat treatment see page 81.

Hot rolled rounds are carried in stock in sizes from $\frac{3}{8}$ " to 6"; and cold drawn bars in sizes $\frac{1}{2}$ " to $1\frac{1}{2}$ ". Forgings can also be furnished. For a complete list of sizes see the current issue of the Ryerson Journal and Stock List or refer to the supplement in the back of this book.

Carbon, 0.15 to 0.25; manganese, 0.50 to 0.80; phosphorous maximum, 0.04 sulphur maximum, 0.045; nickel, 3.25 to 3.75.

S. A. E. 2330—3½ Per Cent Nickel Steel

S. A. E. 2330 is a high carbon $3\frac{1}{2}\%$ nickel steel suitable for axles, shafts and other highly stressed parts. Great strength coupled with medium hardness is obtainable by oil quenching. S. A. E. 2330 has very general all around application. For heat treatment see page 81.

Rounds are carried in stock in sizes from $\frac{3}{8}$ " to 3". For a complete list of stock sizes see the current issue of the Ryerson Journal and Stock List or refer to the supplement in the back of this book.

Carbon, 0.25 to 0.35; manganese, 0.50 to 0.80; phosphorous maximum, 0.04; sulphur, maximum, 0.045; nickel, 3.25 to 3.75.

S. A. E. 2335—3½ Per Cent Nickel Steel

S. A. E. 2335 is very similar to S. A. E. 2330 except that it is a higher carbon steel and develops a greater degree of hardness. For heat treatment see page 81.

Rounds are carried in stock in sizes from $\frac{3}{8}$ " to 3". For a complete list of stock sizes see the current issue of the Ryerson Journal and Stock List or refer to the supplement in the back of this book.

Carbon, 0.30 to 0.40; manganese, 0.50 to 0.80; phosphorous, maximum, 0.04; sulphur maximum, 0.045; nickel, 3.25 to 3.75.

S. A. E. 2345—3½ Per Cent Nickel Steel

S. A. E. 2345 is an oil hardening steel for use where great strength is required. It can be quenched in water to secure extreme hardness. It is widely used for gears, pins, spindles, and other parts requiring a hard wearing surface. For heat treatment see page 81.

Rounds are carried in stock in sizes from $3\frac{1}{4}$ " to 6". For a complete list of stock sizes see the current issue of the Ryerson Journal and Stock List or refer to the supplement in the back of this book.

Carbon, 0.40 to 0.50; manganese, 0.50 to 0.80; phosphorous maximum, 0.04; sulphur maximum, 0.045; nickel, 3.25 to 3.75.

S. A. E. 2350—3½ Per Cent Nickel Steel

S. A. E. 2350 is the same analysis as S. A. E. 2345 except that the carbon is higher and will give a greater degree of hardness when required. For heat treatment see page 81.

Rounds are carried in stock in sizes from $3\frac{1}{4}$ " to 6". For a complete list of stock sizes see the current issue of the Ryerson Journal and Stock List or refer to the supplement in the back of this book.

Carbon, 0.45 to 0.55; manganese, 0.50 to 0.80; phosphorous maximum, 0.04; sulphur maximum, 0.045; nickel, 3.25 to 3.75.

Ryco

A Heat Treated Alloy Steel

(Descriptive Bulletins will be sent on request.)

Ryco is a Ryerson alloy that is tough and strong, yet reasonably low in price. It is carried in stock in the heat treated condition and sold with a guarantee covering physical properties.

Ryco is somewhat more difficult to machine than screw stock yet it cuts freer and cleaner than either chrome nickel or 3½% nickel steel. A very good, smooth finish cut can be taken without difficulty or without special precaution.

While Ryco has high tensile strength and a high yield point, a ¾" round bar can be bent double without fracture. The great value of Ryco, however, is that it comes to you already heat treated with guaranteed physical properties upon which you can depend.

If you have a part to make which must be strong, tough and durable, yet not too expensive, Ryco will probably solve the problem. It is used for many purposes, such as:

Spindles	Gears	Lathe Spindles
Shafts	Tie-rods	Grinding Wheel Spindles
Axles	Machine Tool Parts	Milling Machine Arbors
U-bolts	Agricultural	Conveyor Machinery Arbors
Studs	Machinery Parts	Armature Shafts
Pins	Boring Bars	Power Transmission Parts, etc.

GUARANTEED PHYSICAL PROPERTIES

For All Sizes up to 3¾" Rounds

Minimum tensile strength.....	90,000 lbs. per sq. in.
Minimum yield point.....	70,000 lbs. per sq. in.
Minimum elongation.....	20% in 2 inches.
Minimum reduction of area.....	50%
Approximate Brinell Hardness.....	212-225

GUARANTEED PHYSICAL PROPERTIES

For Sizes Larger than 3¾" Rounds

Minimum tensile strength.....	90,000 lbs. per sq. in.
Minimum yield point.....	60,000 lbs. per sq. in.
Minimum elongation.....	approximately 20%
Minimum reduction of area.....	approximately 35%
Approximate Brinell Hardness.....	212-225

For a complete list of sizes carried in stock see the current issue of the Ryerson Journal and Stock List, or refer to the supplement in the back of this book.

Nikrome

A Heat Treated Alloy Steel

(Descriptive Bulletins will be sent on request.)

Nikrome is a heat treated special analysis alloy steel which has proven remarkably successful for a wide range of heavy duty applications.

It is a chrome nickel steel which will meet S. A. E. specification 3140. This does not mean, however, that the S. A. E. specification will satisfy Nikrome requirements. Nikrome is made from picked heats in which the phosphorus and sulphur are low and the nickel, chrome, manganese, carbon, and other elements are of the proper proportions to develop, after heat treatment, the physical properties which are required of this commodity. Nikrome conforms to the A. S. T. M. specification for high pressure stud and bolt material. It is guaranteed as to these physical properties and also to be free from defects, etc.

It is not offered to the trade as a cheap alloy, but as an alloy that is to be used where strength is the prime requirement and where failure means heavy expense, delay and inconvenience.

The tensile strength and the yield point on Nikrome are high, yet elasticity and ductility have not been sacrificed in obtaining these physical properties. The Brinell Hardness will average around 250, which, while it is hard, is not too hard for regular commercial machining.

Every possible precaution is taken to insure the very highest quality of steel and the best form of heat treatment to produce in Nikrome a product of uniformity and dependability. It has been used successfully for many applications, such as drive shafts, axles, spindles, high duty bolts, roll mandrels, pins, etc.

GUARANTEED PHYSICAL PROPERTIES

Minimum tensile strength.....	125,000 lbs. per sq. in.
Minimum yield point.....	105,000 lbs. per sq. in.
Minimum reduction of area.....	50%
Minimum elongation.....	16% in 2 inches.

Nikrome is carried in stock in both hot rolled and cold drawn rounds. For a complete list of sizes see the current Ryerson Stock List or refer to the supplement in the back of this book.

Cold Finished High Manganese Screw Stock

(Descriptive Bulletins will be sent on request.)

Cold finished high manganese screw stock possesses many properties which are not developed in straight carbon steels, and since these properties are developed by the addition of a high percentage of manganese, we believe that this steel should be considered with the alloys. High magnification of the structure shows a superior and a desirable distribution of elements, which is not found in plain carbon steels.

Manganese, a gray metal, is present in all steels in varying proportions. Used in low percentages, it serves as a deoxidizer and cleanser of the metal. When larger proportions are used special properties are developed in the steel. Since a certain amount of manganese is essential in all carbon steels as a deoxidizer, the excess of this beneficial element is available for alloying with other elements. The right amount of manganese combined with proper percentages of carbon, silicon, phosphorous, sulphur, etc., develops some very valuable characteristics.

Ryerson high manganese screw stock is an open hearth steel. It contains a relatively high percentage of manganese but it retains the free machining qualities characteristic of ordinary screw stock. The user is therefore able to obtain very fine physical properties in case hardened parts and at the same time maintain low costs in the machine shop operations. The physical properties obtained are equivalent to those of the lower priced grades of some of the better known special alloys.

Standard high sulphur bessemer screw stock has extremely good cutting qualities, but the heat treating or case hardening properties are not good. With open hearth screw stock the case hardening properties are better, but machinability is lowered. In Ryerson high manganese the good properties of both these steels are combined.

Extensive experiments indicate that high manganese screw stock can be machined at speeds only about 10 per cent lower than those used for bessemer screw stock and about 15 per cent in excess of those used for S. A. E. 1120. Machinability of this steel as compared to that of S. A. E. 1020 is so far superior that it is hardly necessary to make a comparison.

Ryerson manganese screw stock can be case hardened either by the standard carbonizing process, or by cyanide treatment with either oil or water quenching. The only differences recom-

mended in the heat treatment are that the carbonizing is carried out at about 50 degrees lower temperature; and that a one hour reduction in the carbonizing time required for other steels will give an equal amount of penetration free from the familiar soft spots so frequently found.

A remarkable uniformity of both core and case is developed in this steel. The hardness and wearing properties of the case are in every way equivalent to the straight carbon case hardening steels, and the core strength is actually superior in both tensile strength and toughness.

An idea of the physical properties of this material may be obtained from the following physical property table, which covers some tests on 1" round, Ryerson cold finished high manganese screw stock.

TENSION TESTS

	Tensile Strength	Yield Point	Elongation in 2"	Reduction of Area	Brinell
Hot Rolled, natural condition.....	76,000	45,000	36%	60	160
Cold Drawn, natural condition.....	83,000	55,000	17%	52	175
Water quench 1550° F.					
draw 500° F.	130,000	115,000	11%	36	300
Water quench 1550° F.					
draw 900° F.	110,000	89,000	21%	64	200

TORSION TEST

			Angle of deflection at break 278°
Water quench 1550° F.			
draw 900° F.	110,000	88,000	

It is not our intention to offer this high manganese screw stock to replace on a physical property basis, such higher priced steels as S. A. E. 2315, or S. A. E. 3115, in which much higher physicals are developed, but rather as an intermediate grade between the straight carbon steels and the nickel or chrome nickel steels. The relatively low cost of this material makes it possible to increase the quality of your product, and at the same time maintain a high rate of production on automatic work.

Cold finished high manganese rounds are carried in stock in sizes from $\frac{1}{4}$ " to 3". For a complete list of all sizes carried in stock, see current issue of the Ryerson Journal and Stock List or refer to stock supplement in back of this book.

The Stainless and Heat Resisting Alloys

Allegheny Metal

(Descriptive Bulletins will be sent on request.)

Allegheny metal is a SUPER corrosion resisting nickel chrome alloy. It also has great resistance to oxidation at temperatures ranging up to 1650 degrees Fahrenheit. It retains to a remarkable degree its strength at these high temperatures. It is ductile and malleable and may be drawn and formed, welded and soldered. When polished it takes a beautiful surface, which is easily kept bright and clean by merely washing. It retains this luster and wears indefinitely. Widely used for restaurant, hotel and cafeteria equipment; paper mill machinery, dairy equipment, etc. It is not affected by milk products, fruit juices or most acids.

Allegheny metal contains 17% to 20% chromium and 7% to 10% nickel with very low carbon. It is non-hardening and practically non-magnetic.

Annealed allegheny metal has a tensile strength of approximately 85,000 lbs. per square inch; a yield point of about 45,000 lbs.; elongation of about 60% in 2 inches.

Allegheny metal is produced in all commercial forms including sheets, cold rolled strip, bars, tubes, wire, rivets, bolts, and nuts, etc. For complete list of stocks see the current issue of the Journal and Stock List or turn to the supplement in the back of this book.

Ascoloy 44

(Descriptive Bulletins will be sent on request.)

Ascoloy 44 is a chrome nickel iron alloy which combines maximum heat resistance with facility of fabrication. It is readily bent, formed and welded. This alloy successfully resists oxidation at temperatures up to about 2100 degrees Fahrenheit. It is not embrittled by repeated heating and cooling and retains to a marked extent its high physical properties at these high temperatures.

Ascoloy 44 contains 22 to 25% chromium and 10 to 13% nickel with carbon under 0.20. It can be furnished in plates, sheets, round and square bars, flats, forging blanks, etc. It is used for parts such as pyrometer protection tubes, carbonizing boxes and pots, boiler baffles, etc.

Ascoloy 33

(Descriptive Bulletins will be sent on request.)

Ascoloy 33 is a corrosion resisting, chrome iron alloy. It resists atmospheric corrosion indefinitely and is not affected by many of the chemicals which readily attack iron, steel, copper and non-ferrous alloys.

Ascoloy 33 is stronger than steel and has greater resistance to abrasion and erosion, yet it is ductile, readily machined, and can be welded. It resists oxidation at temperatures up to about 1400 degrees Fahrenheit. When ground and polished it takes a beautiful lustre and in many cases is advantageously substituted for nickel plated steel and brass, also nickel plated alloys. It is economical in price and use.

Ascoloy 33 contains 12% to 16% chromium; manganese under 0.50; silicon under 0.50; carbon under 0.12.

Rough ground and also polished bars; and sheets both white pickled and polished one side are carried in stock for immediate shipment. For a complete list of sizes in stock see the current issue of the Ryerson Journal and Stock List or refer to the supplement in the back of this book.

Ascoloy 66

(Descriptive Bulletins will be sent on request.)

Ascoloy 66 is another chrome-iron heat and corrosion resisting alloy. It is used for temperatures ranging up to about 1700 degrees Fahrenheit and successfully withstands heavy scaling at these heats. It can be readily formed, bent and shaped cold and can also be welded by the oxy-acetylene process. It is particularly resistant to the attack of nitric acid and many other chemicals.

Ascoloy 66 contains 16% to 18% chromium; manganese under 0.50; silicon under 0.50; carbon under 0.12.

Ascoloy 66 retains a large proportion of its strength at elevated temperatures and has a wide field of application.

Ascoloy 55

(Descriptive Bulletins will be sent on request.)

Ascoloy 55 is a chromium-iron heat resisting alloy. It resists oxidation up to about 2150 degrees Fahrenheit and still retains to a marked degree its valuable physical properties.

In addition to its heat resisting qualities ascoloy 55 has remarkable resistance to many corrosive influences.

Ascoloy 55 is machinable but it is not recommended for application involving difficult fabrication. It is successfully used for furnace parts, kiln linings, glass molds, etc.

Ascoloy 55 contains 26% to 30% chromium; manganese under 1%; silicon under 0.60; carbon under 0.25.

It can be furnished in plates, sheets, bars, rods, bolts and nuts.

S. A. E. Specifications

A system of numbers has been adopted for the naming of practically all the standard grades of alloy steels. These numbers give a very convenient way of indicating a certain alloy steel and can be used in sending telegrams, letters, or shop drawings and many other places where a full description of the steel would take up a lot of room.

The first figure indicates the class of steel. The second figure indicates the approximate percentage of the principal alloying element. The last two or three figures represent the carbon desired in one hundredths of one per cent or "points."

The key list of first figures is as follows:

- 1—Carbon Steels.
- 2—Nickel Steels.
- 3—Chrome Nickel Steels.
- 5—Chromium Steels.
- 6—Chrome Vanadium Steels.
- 9—Silico-Manganese Steels.

From the above SAE 3120 is a chrome nickel steel of about 1 per cent (1 to 1½) nickel, carbon 0.20 (15 to 25).

SAE 2335 is a nickel steel of about 3 per cent (3.25-3.75) nickel, carbon 0.35 (30-40).

SAE 6150 is a chrome vanadium steel of about 1 per cent chrome (0.80 to 1.10), carbon 0.50 (45-55).

SAE 51120 is a chromium steel of about 1 per cent chrome (0.90-1.10), carbon 1.20 per cent (1.10-1.30).

S. A. E. Specifications

CARBON STEELS

S. A. E. Steel No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulphur, Max.
1010	0.05-0.15	0.30-0.60	0.045	0.05
1015	0.10-0.20	0.30-0.60	0.045	0.05
1020	0.15-0.25	0.30-0.60	0.045	0.05
1025	0.20-0.30	0.50-0.80	0.045	0.05
1030	0.25-0.35	0.50-0.80	0.045	0.05
1035	0.30-0.40	0.50-0.80	0.045	0.05
1040	0.35-0.45	0.50-0.80	0.045	0.05
1045	0.40-0.50	0.50-0.80	0.045	0.05
1046	0.40-0.50	0.30-0.50	0.045	0.05
1050	0.45-0.55	0.50-0.80	0.045	0.05
1095	0.90-1.05	0.25-0.50	0.040	0.05
1350*	0.45-0.55	0.90-1.20	0.040	0.05
1360*	0.55-0.70	0.90-1.20	0.040	0.05

*The silicon content for steels No. 1350 and 1360 shall not exceed 0.30 per cent.

SCREW STOCK

S. A. E. Steel No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulphur, Range
1112	0.08-0.16	0.60-0.80	0.09-0.13	0.075-0.15
1120	0.15-0.25	0.60-0.90	Max. 0.06	0.075-0.15

STEEL CASTINGS

S. A. E. Steel No.	Carbon	Phosphorus, Max.	Sulphur, Max.
1235	As required by physical properties	0.05	0.05

MOLYBDENUM STEELS*

S. A. E. Steel No.	Carbon Range	Man- gane- se Range	Phos- phorus, Max.	Sul- phur, Max.	Chro- mium Range	Nickel Range	Molyb- denum Range
4130	0.25-0.35	0.40-0.70	0.04	0.045	0.50-0.80	.....	0.15-0.25
4140	0.35-0.45	0.40-0.70	0.04	0.045	0.80-1.10	.....	0.15-0.25
4150	0.45-0.55	0.40-0.70	0.04	0.045	0.80-1.10	.....	0.15-0.25
4615	0.10-0.20	0.30-0.50	0.04	0.045	.....	1.25-1.75	0.20-0.30

*S. A. E. Recommended Practice.

CHROMIUM STEELS

S. A. E. Steel No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulphur, Max.	Chromium Range
5120	0.15-0.25	0.30-0.60	0.04	0.045	0.60-0.90
5140	0.35-0.45	0.50-0.80	0.04	0.045	0.80-1.10
5150	0.45-0.55	0.50-0.80	0.04	0.045	0.80-1.10
52100	0.95-1.10	0.20-0.50	0.03	0.030	1.20-1.50

CHROMIUM-VANADIUM STEELS

S. A. E. Steel No.	Carbon Range	Manganese Range	Phos- phorus, Max.	Sul- phur, Max.	Chromium Range	Vanadium	
						Min.	De- sired
6120	0.15-0.25	0.50-0.80	0.04	0.04	0.80-1.10	0.15	0.18
6125	0.20-0.30	0.50-0.80	0.04	0.04	0.80-1.10	0.15	0.18
6130	0.25-0.35	0.50-0.80	0.04	0.04	0.80-1.10	0.15	0.18
6135	0.30-0.40	0.50-0.80	0.04	0.04	0.80-1.10	0.15	0.18
6140	0.35-0.45	0.50-0.80	0.04	0.04	0.80-1.10	0.15	0.18
6145	0.40-0.50	0.50-0.80	0.04	0.04	0.80-1.10	0.15	0.18
6150	0.45-0.55	0.50-0.80	0.04	0.04	0.80-1.10	0.15	0.18
6195	0.90-1.05	0.20-0.45	0.03	0.03	0.80-1.10	0.15	0.18

TUNGSTEN STEELS

S. A. E. Steel No.	Carbon Range	Man- ganese Max.	Phos- phorus, Max.	Sul- phur, Max.	Chromium Range	Tungsten Range
71360	0.50-0.70	0.30	0.035	0.035	3.00-4.00	12.00-15.00
71660	0.50-0.70	0.30	0.035	0.035	3.00-4.00	15.00-18.00
7260	0.50-0.70	0.30	0.035	0.035	0.50-1.00	1.50-2.00

SILICO-MANGANESE STEELS

S. A. E. Steel No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulphur, Max.	Silicon Range
9250	0.45-0.55	0.60-0.90	0.045	0.045	1.80-2.20
9260	0.55-0.65	0.60-0.90	0.045	0.045	1.80-2.20

NICKEL STEELS

S. A. E. Steel No.	Carbon Range	Manganese Range	Phos- phorus, Max.	Sulphur, Max.	Nickel Range
2315	0.10-0.20	0.30-0.60	0.04	0.045	3.25-3.75
2320	0.15-0.25	0.50-0.80	0.04	0.045	3.25-3.75
2330	0.25-0.35	0.50-0.80	0.04	0.045	3.25-3.75
2335	0.30-0.40	0.50-0.80	0.04	0.045	3.25-3.75
2340	0.35-0.45	0.50-0.80	0.04	0.045	3.25-3.75
2345	0.40-0.50	0.50-0.80	0.04	0.045	3.25-3.75
2350	0.45-0.55	0.50-0.80	0.04	0.045	3.25-3.75
2512	max. 0.17	0.30-0.60	0.04	0.045	4.50-5.25

NICKEL—CHROMIUM STEELS

S. A. E. Steel No.	Carbon Range	Manganese Range	Phos- phorus, Max.	Sul- phur, Max.	Nickel Range	Chromium Range
3115	0.10-0.20	0.30-0.60	0.04	0.045	1.00-1.50	0.45-0.75
3120	0.15-0.25	0.30-0.60	0.04	0.045	1.00-1.50	0.45-0.75
3125	0.20-0.30	0.50-0.80	0.04	0.045	1.00-1.50	0.45-0.75
3130	0.25-0.35	0.50-0.80	0.04	0.045	1.00-1.50	0.45-0.75
3135	0.30-0.40	0.50-0.80	0.04	0.045	1.00-1.50	0.45-0.75
3140	0.35-0.45	0.50-0.80	0.04	0.045	1.00-1.50	0.45-0.75
3215	0.10-0.20	0.30-0.60	0.04	0.040	1.50-2.00	0.90-1.25
3220	0.15-0.25	0.30-0.60	0.04	0.040	1.50-2.00	0.90-1.25
3230	0.25-0.35	0.30-0.60	0.04	0.040	1.50-2.00	0.90-1.25
3240	0.35-0.45	0.30-0.60	0.04	0.040	1.50-2.00	0.90-1.25
3245	0.40-0.50	0.30-0.60	0.04	0.040	1.50-2.00	0.90-1.25
3250	0.45-0.55	0.30-0.60	0.04	0.040	1.50-2.00	0.90-1.25
3312	max. 0.17	0.30-0.60	0.04	0.040	3.25-3.75	1.25-1.75
3325	0.20-0.30	0.30-0.60	0.04	0.040	3.25-3.75	1.25-1.75
3335	0.30-0.40	0.30-0.60	0.04	0.040	3.25-3.75	1.25-1.75
3340	0.35-0.45	0.30-0.60	0.04	0.040	3.25-3.75	1.25-1.75
3415	0.10-0.20	0.45-0.75	0.04	0.040	2.75-3.25	0.60-0.95
3435	0.30-0.40	0.45-0.75	0.04	0.040	2.75-3.25	0.60-0.95
3450	0.45-0.55	0.45-0.75	0.04	0.040	2.75-3.25	0.60-0.95

Definitions

NORMALIZING—A uniform heating above the upper critical temperature followed by cooling freely in air.

ANNEALING—A uniform heating above the upper critical temperature followed by slow cooling as desired.

SPHEROIDIZING—Prolonged heating of iron base alloys at a temperature in the neighborhood of, but generally slightly below, the critical temperature range, usually followed by relatively slow cooling. This process produces a change in condition of the iron carbides.

NOTE A—In the case of small objects of high carbon steels, the spheroidizing result is achieved more rapidly by prolonged heating to temperatures alternately within and slightly below the critical temperature range.

NOTE B—The object of this heat treatment is to produce a globular condition of the carbide.

QUENCHING—The operation of rapidly cooling in a suitable medium.

DRAWING—Reheating after quenching for hardening, to some temperature below the lower limit of the critical range, followed by cooling as desired.

CASE-HARDENING—The operation of carburizing steel to a predetermined depth of case and subjecting it to a subsequent heat-treatment.

CARBURIZING—The operation of causing the absorption of carbon by steel when heated below its melting point in contact with carbonaceous material.

CASE—The outer portion of a carbonized part that has absorbed carbon from the carburizing medium.

CORE—The inner portion of a carbonized part that has not absorbed carbon from the carburizing medium.

CYANIDING—The operation of case-hardening by which the carburizing is accomplished by heating the steel in a melted cyanide salt.

COLD-WORKING—The operation of forming the metal, without the application of heat, by rolling, hammering, drawing, pressing or other means to obtain accurate size, fine finish or increased strength.

HOT-WORKING—The operation of rolling, hammering, pressing or extruding metal which has been made plastic by heating.

YIELD-POINT—The load per unit of original cross-section at which a marked increase in the deformation of the specimen occurs without increase of load. It is usually calculated from the load determined by the drop of the beam of the testing machine or by use of dividers.

ELASTIC LIMIT—The elastic limit is determined by an extensometer reading of .0002 inches. The extensometer is attached to the specimen at the gauge marks and not to the shoulders of the specimen or to any part of the testing machine. When the specimen is in place and the extensometer attached, the testing machine shall be operated so as to increase the load on the specimen at a uniform rate. The load at which the rate of elongation increases suddenly on the extensometer is called the elastic limit.

TENSILE-STRENGTH—The maximum load per unit of original cross-sectional area obtained before rupture.

PERCENTAGE ELONGATION—The percentage of increase in length of a tension test specimen after rupture.

PERCENTAGE REDUCTION OF AREA—The percentage of decrease of cross-sectional area of a tension test-specimen after rupture.

SHORE HARDNESS—The reading of a conventional scale determined by the rebound of the hammer of the Shore scleroscope on striking the surface of the specimen.

BRINELL HARDNESS—The number obtained from the ratio between the load applied on and the spherical area of the impression made by a steel ball forced into the surface of the material tested.

SPECIAL STEELS IN STOCK

POLISHED DRILL RODS—PRICE LIST

For Small Taps, Reamers, Punches, Twist Drills,
Dental Tools, Watch Parts, Electrical
Work, Etc.

No.	Sizes in decimals of an inch	Nearest Sizes in fractions of an inch	Prices per pound	No.	Sizes in decimals of an inch	Nearest Sizes in fractions of an inch	Prices per pound
.....	1.000	1	\$0.50	R	0.339	.....	\$0.75
.....	0.9843	63-64	.50	Q	0.332	.....	.75
.....	0.9687	31-32	.50	.....	0.3281	21-64	.75
.....	0.953	61-64	.50	P	0.323	.....	.75
.....	0.9375	15-16	.50	O	0.316	.....	.75
.....	0.9218	59-64	.50	.....	0.3125	5-16	.75
.....	0.9062	29-32	.50	N	0.302	.....	.75
.....	0.8906	57-64	.50	.....	0.2968	19-64	.75
.....	0.875	$\frac{7}{8}$	.50	M	0.295	.....	.75
.....	0.8593	55-64	.50	L	0.290	.....	.75
.....	0.8437	27-32	.50	.....	0.2812	9-32	.75
.....	0.828	53-64	.50	K	0.281	.....	.75
.....	0.8125	13-16	.50	J	0.277	.....	.75
.....	0.7968	51-64	.50	I	0.272	.....	.75
.....	0.7812	25-32	.50	H	0.266	.....	.75
.....	0.7656	49-64	.50	.....	0.2656	17-64	.75
.....	0.750	$\frac{3}{4}$	.55	G	0.261	.....	.75
.....	0.7343	47-64	.55	F	0.257	.....	.75
.....	0.7187	23-32	.55	E	0.250	.....	.75
.....	0.703	45-64	.55	.....	0.250	$\frac{1}{4}$	.75
.....	0.6875	11-16	.55	D	0.246	.....	.75
.....	0.6718	43-64	.55	C	0.242	.....	.75
.....	0.6562	21-32	.55	B	0.238	.....	.75
.....	0.6406	41-64	.55	.....	0.2343	15-64	.75
.....	0.625	$\frac{5}{8}$	.55	A	0.234	.....	.75
.....	0.6093	39-64	.55	1	0.227	.....	.75
.....	0.5937	19-32	.55	2	0.219	.....	.75
.....	0.578	37-64	.55	.....	0.2187	7-32	.75
.....	0.5625	9-16	.55	3	0.212	.....	.75
.....	0.5468	35-64	.55	4	0.207	.....	.75
.....	0.5312	17-32	.55	5	0.204	.....	.75
.....	0.5156	33-64	.55	.....	0.2031	13-64	.75
.....	0.500	$\frac{1}{2}$	.60	6	0.201	.....	.75
.....	0.4843	31-64	.60	7	0.199	.....	.75
.....	0.4687	15-32	.60	8	0.197	.....	.75
.....	0.4531	29-64	.60	9	0.194	.....	.75
.....	0.4375	7-16	.60	10	0.191	.....	.75
.....	0.4218	27-64	.75	11	0.188	.....	.75
Z	0.413	.....	.75	.....	0.1875	3-16	.75
.....	0.4062	13-32	.75	12	0.185	.....	.75
Y	0.404	.....	.75	13	0.182	.....	.75
X	0.397	.....	.75	14	0.180	.....	.75
.....	0.3906	25-64	.75	15	0.178	.....	.75
W	0.386	.....	.75	16	0.175	.....	.83
V	0.377	.....	.75	17	0.172	.....	.83
.....	0.375	$\frac{3}{8}$	.75	.....	0.1718	11-64	.83
U	0.368	.....	.75	18	0.168	.....	.83
.....	0.3593	23-64	.75	19	0.164	.....	.83
T	0.358	.....	.75	20	0.161	.....	.83
S	0.348	.....	.75	21	0.157	.....	.83
.....	0.3437	11-32	.75	.....	0.1562	5-32	.83

JOSEPH T. RYERSON & SON, INC.

POLISHED DRILL RODS—PRICE LIST—*Continued*
For Small Taps, Reamers, Punches, Twist Drills,
Dental Tools, Watch Parts, Electrical
Work, Etc.

No.	Sizes in decimals of an inch	Nearest Sizes in fractions of an inch	Prices per pound	No.	Sizes in decimals of an inch	Nearest Sizes in fractions of an inch	Prices per pound
22	0.155		\$0.83	66	0.032		\$3.00
23	0.153		.83		0.0312	1-32	3.00
24	0.151		.83	67	0.031		3.00
25	0.148		.83	68	0.030		3.00
26	0.146		.83	69	0.029		3.30
27	0.143		.83	70	0.027		3.30
	0.1406	9-64	.83	71	0.026		3.60
28	0.139		.83	72	0.024		3.60
29	0.134		.83	73	0.023		3.60
30	0.127		.83	74	0.022		3.60
	0.125	1-8	.83	75	0.020		3.90
31	0.120		.90	76	0.018		4.05
32	0.115		.90	77	0.016		4.20
33	0.112		.90		0.0156	1-64	4.50
34	0.110		.90	78	0.015		4.80
	0.1093	7-64	.90	79	0.014		5.10
35	0.108		.90	80	0.013		5.40
36	0.106		.90				
37	0.103		.90				
38	0.101		.90				
39	0.099		1.05				
40	0.097		1.05				
41	0.095		1.05				
	0.0937	3-32	1.05				
42	0.092		1.05				
43	0.088		1.05				
44	0.085		1.05				
45	0.081		1.05				
46	0.079		1.05				
	0.0781	5-64	1.20				
47	0.077		1.20				
48	0.075		1.20				
49	0.072		1.20				
50	0.069		1.20				
51	0.066		1.45				
52	0.063		1.45				
	0.0625	1-16	1.45				
53	0.058		1.45				
54	0.055		1.45				
55	0.050		1.80				
	0.0468	3-64	1.80				
56	0.045		1.80				
57	0.042		1.80				
58	0.041		2.10				
59	0.040		2.10				
60	0.039		2.10				
61	0.038		2.40				
62	0.037		2.40				
63	0.036		2.70				
64	0.035		2.70				
65	0.033		2.70				

SQUARE DRILL RODS
For
Punches, Engravers'
Tools, Dies, Etc.

Size	Decimal Equivalent	Price per Pound
1-16	.0625	\$1.60
3-32	.0937	1.60
$\frac{1}{8}$	.125	1.60
5-32	.1561	1.60
3-16	.1875	1.60
7-32	.2185	1.60
$\frac{1}{4}$	.250	1.60
9-32	.2812	1.60
5-16	.3125	1.60
11-32	.3437	1.60
$\frac{3}{8}$	.375	1.60
13-32	.4062	1.60
7-16	.4375	1.60
$\frac{1}{2}$	.500	1.60
$\frac{5}{8}$	.625	1.60
$\frac{3}{4}$	.750	1.60

SPECIAL STEELS IN STOCK

HIGH SPEED TOOL STEEL—CLASSIFICATION OF NET EXTRAS

ROUNDS, SQUARES AND OCTAGONS

Size in Inches	Price per Lb. Extra	Size in Inches	Price per Lb. Extra
$\frac{5}{8}$ to 2	Base	$5\frac{5}{8}$ to 6	\$0.05½
$2\frac{1}{8}$ to $2\frac{1}{2}$	\$0.02	$6\frac{1}{8}$ to $6\frac{1}{2}$	.06
$2\frac{3}{8}$ to 3	.02½	$6\frac{3}{8}$ to 7	.06½
$3\frac{1}{8}$ to $3\frac{1}{2}$	.03	9-16 to $\frac{1}{2}$	.02
$3\frac{3}{8}$ to 4	.03½	7-16 to $\frac{3}{8}$	.03½
$4\frac{1}{8}$ to $4\frac{1}{2}$	.04	5-16 to 11-32	.06
$4\frac{3}{8}$ to 5	.04½	$\frac{1}{4}$ to 9-32	.08½
$5\frac{1}{8}$ to $5\frac{1}{2}$	.05		

FLATS

Size in Inches	Price per Lb. Extra	Size in Inches	Price per Lb. Extra
$\frac{5}{8}$ to 2 x $\frac{5}{8}$ to 2	Base	$\frac{3}{8}$ x $\frac{7}{8}$ to $1\frac{1}{2}$	\$0.03
$\frac{1}{2}$ x 3-16	\$0.40	$\frac{3}{8}$ x $1\frac{1}{8}$ to 5	.02½
$\frac{1}{2}$ x $\frac{1}{4}$	.30	7-16 x $\frac{1}{2}$ to 1	.03
$\frac{1}{2}$ x 5-16	.20	7-16 x $1\frac{1}{8}$ to $5\frac{1}{2}$	.02½
$\frac{1}{2}$ x $\frac{3}{8}$ to 2	.14	$\frac{1}{2}$ x $\frac{5}{8}$ to 1	.02½
3-16 x $\frac{1}{4}$ to 3	.14	$\frac{1}{2}$ x $1\frac{1}{8}$ to 6	.02
$\frac{1}{4}$ x 5-16 to $\frac{1}{2}$	.08	9-16 x $\frac{5}{8}$ to 1	.02½
$\frac{1}{4}$ x $\frac{5}{8}$ to 1	.05	9-16 x $1\frac{1}{8}$ to 6	.02
$\frac{1}{4}$ x $1\frac{1}{8}$ to 4	.03	$\frac{5}{8}$ to 2 x $2\frac{1}{8}$ to 4	.02
5-16 x $\frac{3}{8}$ to $\frac{5}{8}$	.05	$\frac{5}{8}$ to 2 x $4\frac{1}{8}$ to 7	.04
5-16 x $\frac{3}{4}$ to 1	.03½	$2\frac{1}{8}$ to 3 x $2\frac{1}{8}$ to 4	.02
5-16 x $1\frac{1}{4}$ to $4\frac{1}{2}$	.03	$2\frac{1}{8}$ to 3 x $4\frac{1}{8}$ to 7	.04
$\frac{3}{8}$ x 7-16 to $\frac{3}{4}$	.03		

Intermediate sizes take next higher extra. All dimensions inclusive. Annealing, 2 cents per lb. extra. Bevels, same classification as flats plus 10 cents per lb. for shape.

CUTTING TO SPECIFIED SINGLE AND MULTIPLE LENGTHS

Length in Inches	Extra per Lb.	Length in Inches	Extra per Lb.
Less than 1	\$0.30	5 to 5 15-16	\$0.06
1 to 1 15-16	.20	6 to 11 15-16	.04
2 to 2 15-16	.12	12 to 17 15-16	.03
3 to 3 15-16	.10	18 to 23 15-16	.02
4 to 4 15-16	.08	24 and Over	.01

Annealing, 2 cents per pound extra.

JOSEPH T. RYERSON & SON, INC.

CARBON TOOL STEEL—CLASSIFICATION OF
NET EXTRAS

ROUNDS, SQUARES AND OCTAGONS

Size in Inches	Price per Lb. Extra	Size in Inches	Price per Lb. Extra
$\frac{5}{8}$ to 2	Base	$2\frac{1}{8}$ to 3	\$0 .01
9-16 to $\frac{1}{2}$	\$0 .00 $\frac{1}{2}$	$3\frac{1}{8}$ to 4	.01 $\frac{1}{2}$
7-16 to $\frac{3}{8}$	.01	$4\frac{1}{8}$ to 5	.02
5-16 and 11-32	.02	$5\frac{1}{8}$ to 6	.02 $\frac{1}{2}$
$\frac{1}{4}$ and 9-32	.03	$6\frac{1}{8}$ to 7	.03
3-16	.05	$7\frac{1}{8}$ to 8	.03 $\frac{1}{2}$

FLATS

Size in Inches	Price per Lb. Extra	Size in Inches	Price per Lb. Extra
$\frac{5}{8}$ to 2 x 9-16 to 2	Base	$\frac{1}{4}$ to $7\frac{1}{8}$ to 8	\$0 .02
$\frac{1}{8}$ x 3-16	\$0 .20	5-16 x $\frac{3}{8}$ to $\frac{5}{8}$	.01 $\frac{1}{2}$
$\frac{1}{8}$ x $\frac{1}{4}$	.15	5-16 x 11-16 to 8	.01
$\frac{1}{8}$ x 5-16	.08	$\frac{3}{8}$ x 7-16 to 8	.01
$\frac{1}{8}$ x $\frac{3}{8}$	.04	7-16 x $\frac{1}{2}$ to 8	.01
$\frac{1}{8}$ x 7-16 to $\frac{1}{2}$	.03	$\frac{1}{2}$ x 9-16 to 8	.01
$\frac{1}{8}$ x 9-16 to 7	.02	9-16 x $2\frac{1}{2}$ to 8	.01
$\frac{1}{8}$ x $7\frac{1}{8}$ to 8	.03	$\frac{5}{8}$ to 2 x $2\frac{1}{8}$ to 7	.01
3-16 x $\frac{1}{4}$	.05	$\frac{5}{8}$ to $1\frac{3}{4}$ x $7\frac{1}{8}$ to 8	.01
3-16 x 5-16	.04	$1\frac{1}{8}$ to 2 x $7\frac{1}{8}$ to 8	.01 $\frac{1}{2}$
3-16 x $\frac{3}{8}$	.03	$2\frac{1}{8}$ to 3 x $2\frac{1}{8}$ to 5	.01
3-16 x 7-16 to $\frac{5}{8}$	.02	$2\frac{1}{8}$ to 3 x $5\frac{1}{8}$ to 8	.01 $\frac{1}{2}$
3-16 x 11-16 to 2	.01 $\frac{1}{2}$	$3\frac{1}{8}$ to 4 x $3\frac{1}{8}$ to 6	.01 $\frac{1}{2}$
3-16 x $2\frac{1}{8}$ to 7	.01 $\frac{1}{2}$	$3\frac{1}{8}$ to 4 x $6\frac{1}{8}$ to 8	.02
3-16 x $7\frac{1}{8}$ to 8	.02	$4\frac{1}{8}$ to 5 x $4\frac{1}{8}$ to 7	.02
$\frac{1}{4}$ x 5-16 to $\frac{3}{8}$	.02	$4\frac{1}{8}$ to 5 x $7\frac{1}{8}$ to 8	.02 $\frac{1}{2}$
$\frac{1}{4}$ x 7-16 to $\frac{5}{8}$	.01 $\frac{1}{2}$	$5\frac{1}{8}$ to 6 x $5\frac{1}{8}$ to 8	.02 $\frac{1}{2}$
$\frac{1}{4}$ x 11-16 to 2	.01 $\frac{1}{2}$	$6\frac{1}{8}$ to 7 x $6\frac{1}{8}$ to 7	.03
$\frac{1}{4}$ x $2\frac{1}{8}$ to 7	.01	$6\frac{1}{8}$ to 8 x $7\frac{1}{8}$ to 8	.03 $\frac{1}{2}$

Intermediate sizes take the next higher price.

CUTTING TO SPECIFIED SINGLE AND MULTIPLE
LENGTHS

Length in Inches	Extra per Lb.	Length in Inches	Extra per Lb.
Less than 1	\$0 .15	5 to 5 15-16	\$0 .03
1 to 1 15-16	.10	6 to 11 15-16	.02
2 to 2 15-16	.06	12 to 17 15-16	.01 $\frac{1}{2}$
3 to 3 15-16	.05	18 to 23 15-16	.01
4 to 4 15-16	.04	24 and Over	.00 $\frac{1}{2}$

Annealing, 1 cent per pound extra.

SPECIAL STEELS IN STOCK

CONVERSION TABLES OF FAHRENHEIT AND CENTIGRADE SCALES

Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
0	32	230	446	460	860	690	1274	920	1688	1150	2102	1380	2516
5	41	235	455	465	869	695	1283	925	1697	1155	2111	1385	2525
10	50	240	464	470	878	700	1292	930	1706	1160	2120	1390	2534
15	59	245	473	475	887	705	1301	935	1715	1165	2129	1395	2543
20	68	250	482	480	896	710	1310	940	1724	1170	2138	1400	2552
25	77	255	491	485	905	715	1319	945	1733	1175	2147	1405	2561
30	86	260	500	490	914	720	1328	950	1742	1180	2156	1410	2570
35	95	265	509	495	923	725	1337	955	1751	1185	2165	1415	2579
40	104	270	518	500	932	730	1346	960	1760	1190	2174	1420	2588
45	113	275	527	505	941	735	1355	965	1769	1195	2183	1425	2597
50	122	280	536	510	950	740	1364	970	1778	1200	2192	1430	2606
55	131	285	545	515	959	745	1373	975	1787	1205	2201	1435	2615
60	140	290	554	520	968	750	1382	980	1796	1210	2210	1440	2624
65	149	295	563	525	977	755	1391	985	1805	1215	2219	1445	2633
70	158	300	572	530	986	760	1400	990	1814	1220	2228	1450	2642
75	167	305	581	535	995	765	1409	995	1823	1225	2237	1455	2651
80	176	310	590	540	1004	770	1418	1000	1832	1230	2246	1460	2660
85	185	315	599	545	1013	775	1427	1005	1841	1235	2255	1465	2669
90	194	320	608	550	1022	780	1436	1010	1850	1240	2264	1470	2678
95	203	325	617	555	1031	785	1445	1015	1859	1245	2273	1475	2687
100	212	330	626	560	1040	790	1454	1020	1868	1250	2282	1480	2696
105	221	335	635	565	1049	795	1463	1025	1877	1255	2291	1485	2705
110	230	340	644	570	1058	800	1472	1030	1886	1260	2300	1490	2714
115	239	345	653	575	1067	805	1481	1035	1895	1265	2309	1495	2723
120	248	350	662	580	1076	810	1490	1040	1904	1270	2318	1500	2732
125	257	355	671	585	1085	815	1499	1045	1913	1275	2327	1505	2741
130	266	360	680	590	1094	820	1508	1050	1922	1280	2336	1510	2750
135	275	365	689	595	1103	825	1517	1055	1931	1285	2345	1515	2759
140	284	370	698	600	1112	830	1526	1060	1940	1290	2354	1520	2768
145	293	375	707	605	1121	835	1535	1065	1949	1295	2363	1525	2777
150	302	380	716	610	1130	840	1544	1070	1958	1300	2372	1530	2786
155	311	385	725	615	1139	845	1553	1075	1967	1305	2381	1535	2795
160	320	390	734	620	1148	850	1562	1080	1976	1310	2390	1540	2804
165	329	395	743	625	1157	855	1571	1085	1985	1315	2399	1545	2813
170	338	400	752	630	1166	860	1580	1090	1994	1320	2408	1550	2822
175	347	405	761	635	1175	865	1589	1095	2003	1325	2417	1555	2831
180	356	410	770	640	1184	870	1598	1100	2012	1330	2426	1560	2840
185	365	415	779	645	1193	875	1607	1105	2021	1335	2435	1565	2849
190	374	420	788	650	1202	880	1616	1110	2030	1340	2444	1570	2858
195	383	425	797	655	1211	885	1625	1115	2039	1345	2453	1575	2867
200	392	430	806	660	1220	890	1634	1120	2048	1350	2462	1580	2876
205	401	435	815	665	1229	895	1643	1125	2057	1355	2471	1585	2885
210	410	440	824	670	1238	900	1652	1130	2066	1360	2480	1590	2894
215	419	445	833	675	1247	905	1661	1135	2075	1365	2489	1595	2903
220	428	450	842	680	1256	910	1670	1140	2084	1370	2498	1600	2912
225	437	455	851	685	1265	915	1679	1145	2093	1375	2507		

COMPARATIVE TABLE OF GAUGES IN COMMON USE

Dimensions of Sizes in Decimal Parts of an Inch

Number of Wire Gauge	American or Brown & Sharpe	Birmingham, or Stubs' Iron Wire	Washburn & Moens, Worcester, Mass.	W. & M. Steel Music Wire	New American S. & W. Co.'s Music Wire Gauge	Imperial Wire Gauge	Stubs' Steel Wire	U. S. Standard Gauge for Sheet and Plate Iron and Steel
00000000				.0083				
00000000				.0087				
0000000				.0095				
00000				.010	.004	.464		.46875
0000	.460	.454	.3938	.011	.005	.432		.4375
000	.40964	.425	.3625	.012	.007	.372		.40625
00	.3648	.380	.3310	.0133	.008	.348		.375
0	.32486	.340	.3065	.0144	.009	.324		.34375
1	.2893	.300	.2830	.0156	.010	.300	.227	.3125
2	.25763	.284	.2625	.0166	.011	.276	.219	.28125
3	.22942	.259	.2437	.0178	.012	.252	.212	.265625
4	.20431	.238	.2253	.0188	.013	.232	.207	.250
5	.18194	.220	.2070	.0202	.014	.212	.204	.234375
6	.16202	.203	.1920	.0215	.016	.192	.201	.21875
7	.14428	.180	.1770	.023	.018	.176	.199	.203125
8	.12849	.165	.1620	.0243	.020	.160	.197	.1875
9	.11443	.148	.1483	.0256	.022	.144	.194	.171875
10	.10189	.134	.1350	.027	.024	.128	.191	.15625
11	.090742	.120	.1205	.0284	.026	.116	.188	.140625
12	.080808	.109	.1055	.0296	.029	.104	.185	.125
13	.071961	.095	.0915	.0314	.031	.092	.182	.109375
14	.064084	.083	.0800	.0326	.033	.080	.180	.09375
15	.057068	.072	.0720	.0345	.035	.072	.178	.078125
16	.05082	.065	.0625	.036	.037	.064	.175	.0703125
17	.045257	.058	.0540	.0377	.039	.056	.172	.0625
18	.040303	.049	.0475	.0395	.041	.048	.168	.05625
19	.03589	.042	.0410	.0414	.043	.040	.164	.050
20	.031961	.035	.0348	.0434	.045	.036	.161	.04375
21	.028462	.032	.03175	.046	.047	.032	.157	.0375
22	.025347	.028	.0286	.0483	.049	.028	.155	.034375
23	.022571	.025	.0258	.051	.051	.024	.153	.03125
24	.0201	.022	.0230	.055	.055	.022	.151	.028125
25	.0179	.020	.0204	.0586	.059	.020	.148	.025
26	.01594	.018	.0181	.0626	.063	.018	.146	.021875
27	.014195	.016	.0173	.0658	.067	.0164	.143	.01875
28	.012641	.014	.0162	.072	.071	.0149	.139	.0171875
29	.011257	.013	.0150	.076	.075	.0136	.134	.015625
30	.010025	.012	.0140	.080	.080	.0124	.127	.0140625
31	.008928	.010	.0132		.085	.0116	.120	.0125
32	.00795	.009	.0128		.090	.0108	.115	.0109375
33	.00708	.008	.0118		.095	.0100	.112	.01015625
34	.006304	.007	.0104			.0092	.110	.009375
35	.005614	.005	.0095			.0084	.108	.00859375
36	.005	.004	.0090			.0076	.106	.0078125
37	.004453					.0068	.103	.00703125
38	.003965					.0060	.101	.006640625
39	.003531					.0052	.099	.00625
40	.003144					.0048	.097	

SPECIAL STEELS IN STOCK

WEIGHTS OF IRON AND STEEL

STANDARD GAUGES

No. of Gauge	U. S. STANDARD GAUGE			BIRMINGHAM WIRE GAUGE			
	Approximate Thickness in Inches		Weight Square Foot	No. of Gauge	Thick- ness in Inches	Weight Square Foot	
	Fractions	Decimals				Iron	Steel
7-o's	1-2	.5	20.00	.....	.....	.....	.....
6-o's	15-32	.46875	18.75	.....	.....	.....	.....
5-o's	7-16	.4375	17.50	.....	.....	.....	.....
0000	13-32	.40625	16.25	0000	.454	18.22	18.46
000	3-8	.375	15.	000	.425	17.05	17.28
00	11-32	.34375	13.75	00	.38	15.25	15.45
0	5-16	.3125	12.50	0	.34	13.64	13.82
1	9-32	.28125	11.25	1	.3	12.04	12.20
2	17-64	.265625	10.625	2	.284	11.40	11.55
3	1-4	.25	10.	3	.259	10.39	10.53
4	15-64	.234375	9.375	4	.238	9.55	9.68
5	7-32	.21875	8.75	5	.22	8.83	8.95
6	13-64	.203125	8.125	6	2.03	8.15	8.25
7	3-16	.1875	7.5	7	.18	7.22	7.32
8	11-64	.171875	6.875	8	.165	6.62	6.71
9	5-32	.15625	6.25	9	.148	5.94	6.02
10	9-64	.140625	5.625	10	.134	5.38	5.45
11	1-8	.125	5.	11	.12	4.82	4.88
12	7-64	.109375	4.375	12	.109	4.37	4.43
13	3-32	.09375	3.75	13	.095	3.81	3.86
14	5-64	.078125	3.125	14	.083	3.33	3.37
15	9-128	.0703125	2.8125	15	.072	2.89	2.93
16	1-16	.0625	2.5	16	.065	2.61	2.64
17	9-160	.05625	2.25	17	.058	2.33	2.36
18	1-20	.05	2.	18	.049	1.97	1.99
19	7-160	.04375	1.75	19	.042	1.69	1.71
20	3-80	.037	1.50	20	.035	1.40	1.42
21	11-320	.03475	1.375	21	.032	1.28	1.30
22	1-32	.03125	1.25	22	.028	1.12	1.14
23	9-320	.028125	1.125	23	.025	1.00	1.02
24	1-40	.025	1.	24	.022	.883	.895
25	7-320	.021875	.865	25	.02	.803	.813
26	3-160	.01875	.75	26	.018	.722	.732
27	11-640	.0171875	.6875	27	.016	.642	.651
28	1-64	.015625	.625	28	.014	.562	.569
29	9-640	.0140625	.5625	29	.013	.....	.....
30	1-80	.0125	.5	30	.012	.....	.....
31	7-640	.010985	.4375	31	.01	.....	.....
32	13-1280	.01045625	.40625	32	.009	.....	.....
33	3-320	.009375	.375	33	.008	.....	.....
34	11-1280	.00859375	.34375	34	.007	.....	.....
35	5-640	.0078125	.3125	35	.005	.....	.....
36	9-1280	.00703125	.28125	36	.004	.....	.....
37	17-2560	.00664062	.265625	.....	.....	.....	.....
38	1-160	.00625	.25	.....	.....	.....	.....

ROUND, SQUARE AND OCTAGON BAR STEEL— WEIGHT PER LINEAL FOOT*

Size	Round	Square	Octagon	Size	Round	Square	Octagon
$\frac{1}{16}$	.010	.013	.011	2	10.68	13.60	11.29
$\frac{1}{8}$	.042	.053	.044	$\frac{1}{16}$	11.36	14.46	12.00
$\frac{3}{16}$	.094	.119	.099	$\frac{1}{8}$	12.06	15.35	12.74
$\frac{1}{4}$	.167	.212	.176	$\frac{3}{16}$	12.78	16.27	13.50
$\frac{5}{16}$	.261	.333	.276	$\frac{1}{4}$	13.52	17.22	14.29
$\frac{3}{8}$	.375	.478	.397	$\frac{5}{16}$	14.28	18.19	15.10
$\frac{7}{16}$	.511	.651	.540	$\frac{3}{8}$	15.07	19.18	15.92
$\frac{1}{2}$	.667	.850	.706	$\frac{7}{16}$	15.86	20.20	16.77
$\frac{9}{16}$	.845	1.076	.893	$\frac{1}{2}$	16.69	21.25	17.64
$\frac{5}{8}$	1.043	1.328	1.102	$\frac{9}{16}$	17.53	22.33	18.53
$\frac{11}{16}$	1.262	1.608	1.335	$\frac{5}{8}$	18.40	23.43	19.45
$\frac{3}{4}$	1.502	1.913	1.588	$\frac{11}{16}$	19.29	24.56	20.38
$\frac{13}{16}$	1.763	2.245	1.863	$\frac{3}{4}$	20.20	25.00	20.75
$\frac{7}{8}$	2.044	2.603	2.161	$\frac{13}{16}$	21.12	26.90	22.33
$\frac{15}{16}$	2.347	2.989	2.481	$\frac{7}{8}$	22.07	28.10	23.32
1	2.670	3.400	2.822	$\frac{15}{16}$	23.04	29.34	24.35
$\frac{1}{16}$	3.014	3.838	3.186	3	24.03	30.60	25.40
$\frac{1}{8}$	3.379	4.303	3.572	$\frac{1}{16}$	25.04	31.89	26.47
$\frac{3}{16}$	3.766	4.795	3.980	$\frac{1}{8}$	26.08	33.20	27.56
$\frac{1}{4}$	4.173	5.312	4.409	$\frac{3}{16}$	27.13	34.55	28.68
$\frac{5}{16}$	4.600	5.857	4.861	$\frac{1}{4}$	28.20	35.92	29.81
$\frac{3}{8}$	5.049	6.428	5.335	$\frac{5}{16}$	29.30	37.31	30.97
$\frac{7}{16}$	5.518	7.026	5.832	$\frac{3}{8}$	30.42	38.73	32.15
$\frac{1}{2}$	6.008	7.650	6.350	$\frac{7}{16}$	31.56	40.18	33.35
$\frac{9}{16}$	6.520	8.301	6.890	$\frac{1}{2}$	32.71	41.65	34.57
$\frac{5}{8}$	7.051	8.978	7.452	$\frac{9}{16}$	33.90	43.14	35.81
$\frac{11}{16}$	7.604	9.682	8.036	$\frac{5}{8}$	35.09	44.68	37.08
$\frac{3}{4}$	8.178	10.41	8.640	$\frac{11}{16}$	36.31	46.24	38.38
$\frac{13}{16}$	8.773	11.17	9.271	$\frac{3}{4}$	37.56	47.82	39.69
$\frac{7}{8}$	9.388	11.95	9.919	$\frac{13}{16}$	38.81	49.42	41.02
$\frac{15}{16}$	10.02	12.76	10.59	$\frac{7}{8}$	40.10	51.05	42.37
				$\frac{15}{16}$	41.40	52.71	43.75

*The weight of High Speed Steel is approximately 15% heavier.

SPECIAL STEELS IN STOCK

**ROUND, SQUARE AND OCTAGON BAR STEEL—
WEIGHT PER LINEAL FOOT—Continued***

Size	Round	Square	Octagon	Size	Round	Square	Octagon
4	42.73	54.40	45.15	6	96.14	122.4	101.6
$\frac{1}{16}$	44.07	56.11	46.57	$\frac{1}{16}$	98.14	125.0	103.8
$\frac{1}{8}$	45.44	57.85	48.02	$\frac{1}{8}$	100.2	127.6	105.9
$\frac{3}{16}$	46.83	59.62	49.48	$\frac{3}{16}$	102.2	130.2	108.1
$\frac{1}{4}$	48.24	61.41	50.97	$\frac{1}{4}$	104.3	132.8	110.2
$\frac{5}{16}$	49.66	63.23	52.48	$\frac{5}{16}$	106.4	135.5	112.47
$\frac{3}{8}$	51.11	65.08	54.02	$\frac{3}{8}$	108.5	138.2	114.7
$\frac{7}{16}$	52.58	66.95	55.57	$\frac{7}{16}$	110.7	140.9	116.9
$\frac{1}{2}$	54.07	68.85	57.15	$\frac{1}{2}$	112.8	143.6	119.2
$\frac{9}{16}$	55.59	70.78	58.75	$\frac{9}{16}$	114.9	146.5	121.6
$\frac{5}{8}$	57.12	72.73	60.37	$\frac{5}{8}$	117.2	149.2	123.8
$\frac{11}{16}$	58.67	74.70	62.00	$\frac{11}{16}$	119.4	152.1	126.2
$\frac{3}{4}$	60.25	76.71	63.67	$\frac{3}{4}$	121.7	154.9	128.6
$\frac{13}{16}$	61.84	78.74	65.35	$\frac{13}{16}$	123.9	157.8	131.0
$\frac{7}{8}$	63.46	80.81	67.07	$\frac{7}{8}$	126.2	160.8	133.5
$\frac{15}{16}$	65.10	82.89	68.80	$\frac{15}{16}$	128.5	163.6	135.8
5	66.76	85.00	70.55	7	130.9	166.6	138.3
$\frac{1}{16}$	68.44	87.14	72.33	$\frac{1}{16}$	133.2	169.6	140.8
$\frac{1}{8}$	70.14	89.30	74.12	$\frac{1}{8}$	135.6	172.6	143.3
$\frac{3}{16}$	71.86	91.49	75.94	$\frac{3}{16}$	137.9	175.6	145.7
$\frac{1}{4}$	73.60	93.72	77.79	$\frac{1}{4}$	140.4	178.7	148.3
$\frac{5}{16}$	75.37	95.96	79.65	$\frac{5}{16}$	142.8	181.8	150.8
$\frac{3}{8}$	77.15	98.23	81.53	$\frac{3}{8}$	145.3	184.9	153.5
$\frac{7}{16}$	78.95	100.5	83.42	$\frac{7}{16}$	147.7	188.1	156.1
$\frac{1}{2}$	80.77	102.8	85.32	$\frac{1}{2}$	150.2	191.3	158.8
$\frac{9}{16}$	82.62	105.2	87.31	$\frac{9}{16}$	155.2	197.7	164.2
$\frac{5}{8}$	84.49	107.6	89.31	$\frac{5}{8}$	160.3	204.2	169.5
$\frac{11}{16}$	86.38	110.0	91.30	$\frac{11}{16}$	165.6	210.8	175.0
$\frac{3}{4}$	88.29	112.4	93.29	$\frac{3}{4}$	171.0	217.6	180.6
$\frac{13}{16}$	90.22	114.9	95.37	8	218.4	275.6	227.8
$\frac{7}{8}$	92.17	117.4	97.44	9	267.2	340.0	282.4
$\frac{15}{16}$	94.14	119.9	99.52	10	323.0	411.2	340.6
				11	384.4	489.6	405.8
				12			

*The weight of High Speed Steel is approximately 15% heavier.

FLAT BAR STEEL—WEIGHT PER LINEAL FOOT*

	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$
$\frac{1}{8}$	.213	.266	.320	.372	.426	.479	.530	.585	.640	.745	.850	.955
$\frac{3}{16}$	.319	.399	.480	.558	.639	.718	.790	.878	.960	1.12	1.28	1.43
$\frac{1}{4}$	.425	.533	.640	.743	.852	.958	1.06	1.17	1.28	1.49	1.70	1.91
$\frac{5}{16}$	.531	.665	.800	.929	1.06	1.20	1.33	1.46	1.60	1.86	2.13	2.39
$\frac{3}{8}$	.638	.798	.960	1.12	1.28	1.43	1.59	1.75	1.91	2.23	2.55	2.87
$\frac{7}{16}$	.744	.931	1.12	1.30	1.49	1.67	1.86	2.05	2.23	2.60	2.98	3.35
$\frac{1}{2}$	.....	1.07	1.28	1.49	1.70	1.91	2.13	2.34	2.55	2.98	3.40	3.83
$\frac{9}{16}$	.....	1.20	1.44	1.67	1.91	2.15	2.39	2.63	2.87	3.35	3.83	4.30
$\frac{5}{8}$	.....	.....	1.60	1.86	2.12	2.39	2.66	2.92	3.19	3.72	4.26	4.79
$\frac{11}{16}$	.....	.....	1.76	2.04	2.34	2.63	2.92	3.22	3.51	4.09	4.68	5.26
$\frac{3}{4}$	.....	.....	.....	2.23	2.55	2.86	3.19	3.50	3.83	4.46	5.10	5.74
$\frac{13}{16}$	.....	.....	.....	2.41	2.76	3.11	3.45	3.80	4.14	4.83	5.53	6.22
$\frac{7}{8}$	.....	.....	.....	.....	2.98	3.34	3.72	4.09	4.46	5.21	5.96	6.70
$\frac{15}{16}$	.....	.....	.....	.....	3.19	3.59	3.98	4.38	4.78	5.58	6.38	7.17
1	.....	.....	.....	.....	.....	3.82	4.25	4.68	5.10	5.96	6.80	7.66
$1\frac{1}{8}$	.....	.....	.....	.....	.....	.....	4.78	5.27	5.74	6.71	7.65	8.61
$1\frac{1}{4}$	.....	.....	.....	.....	.....	.....	.....	5.85	6.38	7.45	8.50	9.57
$1\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	7.02	7.67	8.94	10.21	11.49

*The weight of High Speed Steel is approximately 15% heavier.

FLAT BAR STEEL—WEIGHT PER LINEAL FOOT—Continued*

	2½	2¾	3	3½	4	5	6	7	8	9	10	11	12
1/8	1.07	1.18	1.28	1.49	1.70	2.13	2.56	2.98	3.40	3.84	4.26	4.68	5.10
3/16	1.60	1.76	1.92	2.24	2.55	3.20	3.83	4.47	5.10	5.74	6.38	7.02	7.65
1/4	2.13	2.34	2.56	2.98	3.40	4.26	5.11	5.96	6.80	7.65	8.50	9.34	10.20
5/16	2.66	2.92	3.19	3.72	4.25	5.32	6.38	7.44	8.50	9.56	10.62	11.68	12.75
3/8	3.20	3.51	3.83	4.46	5.10	6.40	7.66	8.92	10.20	11.48	12.75	14.03	15.30
7/16	3.72	4.09	4.46	5.21	5.95	7.44	8.92	10.40	11.90	13.40	14.88	16.36	17.85
1/2	4.26	4.68	5.10	5.96	6.80	8.52	10.20	11.90	13.60	15.30	17.00	18.70	20.40
9/16	4.78	5.26	5.74	6.69	7.65	9.56	11.50	13.40	15.30	17.22	19.14	21.02	22.95
5/8	5.32	5.86	6.39	7.44	8.52	10.64	12.78	14.90	17.00	19.13	21.25	23.38	25.50
11/16	5.84	6.43	7.01	8.18	9.35	11.70	14.00	16.40	18.70	21.04	23.38	25.70	28.05
3/4	6.40	7.02	7.65	8.92	10.20	12.80	15.30	17.90	20.40	22.96	25.50	28.05	30.60
13/16	6.91	7.60	8.29	9.67	11.10	13.80	16.60	19.30	22.10	24.86	27.62	30.40	33.15
7/8	7.46	8.19	8.94	10.42	11.92	14.92	17.88	20.80	23.80	26.78	29.75	32.72	35.70
15/16	7.97	8.77	9.56	11.20	12.80	15.90	19.10	22.40	25.50	28.69	31.88	35.06	38.25
1	8.52	9.36	10.20	11.92	13.60	17.04	20.40	23.80	27.20	30.60	34.00	37.40	40.80
1 1/8	9.59	10.54	11.48	13.41	15.30	19.17	22.95	26.80	30.60	34.43	38.25	42.08	45.90
1 1/4	10.65	11.71	12.76	14.90	17.00	21.30	25.61	29.76	34.00	38.26	42.50	46.76	51.00
1 1/2	12.78	14.04	15.30	17.88	20.40	25.56	30.60	35.70	40.80	45.90	51.00	56.10	61.20

*The weight of High Speed Steel is approximately 15% heavier.

JOSEPH T. RYERSON & SON, INC.

DECIMALS OF AN INCH FOR EACH 1-64TH

32nds	64ths	Decimal	Fraction	32nds	64ths	Decimal	Fraction
	1	.015625			33	.515625	
1	2	.03125		17	34	.53125	
	3	.046875			35	.546875	
2	4	.0625	1-16	18	36	.5625	9-16
	5	.078125			37	.578125	
3	6	.09375		19	38	.59375	
	7	.109375			39	.609375	
4	8	.125	1-8	20	40	.625	5-8
	9	.140625			41	.640625	
5	10	.15625		21	42	.65625	
	11	.171875			43	.671875	
6	12	.1875	3-16	22	44	.6875	11-16
	13	.203125			45	.703125	
7	14	.21875		23	46	.71875	
	15	.234375			47	.734375	
8	16	.25	1-4	24	48	.75	3-4
	17	.265625			49	.765625	
9	18	.28125		25	50	.78125	
	19	.296875			51	.796875	
10	20	.3125	5-16	26	52	.8125	13-16
	21	.328125			53	.828125	
11	22	.34375		27	54	.84375	
	23	.359375			55	.859375	
12	24	.375	3-8	28	56	.875	3-8
	25	.390625			57	.890625	
13	26	.40625		29	58	.90625	
	27	.421875			59	.921875	
14	28	.4375	7-16	30	60	.9375	15-16
	29	.453125			61	.953125	
15	30	.46975		31	62	.96875	
	31	.484375			63	.984375	
16	32	.5	1-2	32	64	1.	

Trade Customs

QUOTATIONS

All quotations are subject to change without notice, and all sales are made subject to strikes, accidents, or other unavoidable delays.

We reserve the right to cancel contracts not fully specified in time agreed upon.

Special material is not subject to cancellation without our written consent.

CONFIRMATION ORDERS

Confirming orders should be marked "Confirmation," preferably across face of order. Confirmation orders not so marked may be treated as original open orders and duplicated; in such cases we will not be responsible for expense and inconvenience incurred.

TERMS

Our terms are 30 days net, $\frac{1}{2}$ of 1% for cash in 10 days from date of invoice. All payments to be made by bank draft on Chicago or New York, U. S. Treasury notes or their equivalent. Strangers should accompany their first order with cash or references.

DELIVERIES

Material from warehouse is usually shipped the day order is received.

Orders by telephone are accepted at the risk of the sender, as shipments made before receipt of confirmation are for the service of the customer.

Promises on special work or material from mill are as closely estimated as possible, and we use our best efforts to ship within the time, but can not guarantee to do so.

GUARANTEE

All Ryerson Steels are guaranteed to give satisfactory service when used for the purpose for which sold and when accorded correct treatment.

Owing to the fact that the labor involved in working up steel frequently amounts to more than the invoice value of the steel, we can not agree to settle claims on the basis of involved labor or damage. We will, however, gladly replace defective steel or issue credit to cover.

Other Steels

In addition to the tool and alloy steels shown in this booklet, we can ship immediately almost any kind, shape or size of steel desired.

Standard cold rolled shafting; cold finished, S. A. E. 1020 and 1035; polished and ground shafting, and screw stock are carried in a complete range of sizes. Stocks also include bars, shapes, plates, tubes and "a thousand and one" other common and special steel products.

The Ryerson Journal and Stock List is the guide to these large stocks of steel. It contains the stock sizes, weights, extras and average stock carried on hand. If you are not already getting it, we shall be pleased to place your name on our mailing list to receive it regularly.

Other Ryerson Publications

We also publish other booklets of information along various lines. Any of these will be sent free upon your request.

Machinery Catalog

Small Metal Working Tools

Special Products Catalog

General Data

Structural Tables

Glyco Babbitt Metal

Lewis Refined Iron

Also literature on various special subjects and products.

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